VESTIGES

OF THE

MOLTEN GLOBE.

PART II.

THE EARTH'S SURFACE FEATURES

AND

VOLCANIC PHENOMENA.

BY

WM. LOWTHIAN GREEN.

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PREFACE AND PRELIMINARY REMARKS.

ERRATA.

Page 42—18th line from bottom, for *effect* read *affect*.

Page 55—7th line for *explique* read *expliquer*.

Page 55—4th line for *planiete* read *planete*.

Page 99—The inverted commas marking end of quotation from Bischof after *it* at end of 16th line, should be placed after *fusion* in the 4th line.

Page 143—At end of first note, for page 189 read page 135.

Page 223—In last line on note, for page 84 read page 61.

Page 286—In Tabular Statement of Eruptions, in 1st, 2d and 4th lines for *lava's* read *lavas*. For *premonitary* read *premonitory*.

N. B.—The type for French accents not being available, the accents in French quotations are unavoidably omitted.

…, and combine the two proposed divisions of the subject into one under the title of "The Earth's Surface Features and Volcanic Phenomena,"—the main idea intended to be indicated by this title being, the intimate relation which appears to exist between the rotating earth's configuration and surface features, and volcanic phenomena, the whole subject being truly physiographic. In my first attempt at interpreting the meaning of the earth's surface features—in connection with the earth's figure—I have been accused of making a large induction from small premises, and one of my

PREFACE AND PRELIMINARY REMARKS.

IN Part I., of the Vestiges of the Molten Globe, published in 1875, I proposed to consider in Part II., volcanic action in connection with the great active volcanoes of the Hawaiian Group, leaving Physiography for a third and separate part.

Further consideration induces me to unite the proposed second and third parts in one, and for the present to consider volcanic action and what I there called Physiography, together. Since that date the term physiography, which seemed rather to mean a description of the earth's surface features, has been appropriated by some of our best writers, as expressing a description of the universe, or at least, of the broader aspects of nature generally; and certainly the word may well bear that construction, although it has been suggested that cosmography might be a better term for this, leaving physiography to its former more restricted signification. However, as now commonly used, the term seems to comprise somewhat more than I intended to express by it. I therefore abandon the exact form which I had marked out for myself, and combine the two proposed divisions of the subject into one under the title of "The Earth's Surface Features and Volcanic Phenomena,"—the main idea intended to be indicated by this title being, the intimate relation which appears to exist between the rotating earth's configuration and surface features, and volcanic phenomena, the whole subject being truly physiographic. In my first attempt at interpreting the meaning of the earth's surface features—in connection with the earth's figure—I have been accused of making a large induction from small premises, and one of my

critics, in noticing it, somewhat impatiently demanded "more facts." It should not be forgotten however, that any good globe, or map of the world, represents a stupendous array of facts, which have required the united exertions of the best men in the most enlightened nations of the earth for centuries to collect. But they are precisely the class of facts that were needed in the enquiry; facts however, which have remained almost unnoticed and unused, so far as any important general conclusion has heretofore resulted from their consideration. As Carl Ritter says, "geopraphical treatises form a mere aggregation and index of rich materials, a lexicon rather than a true text-book." *

I did my best to illustrate these "rich materials," and exhibit their meaning by numerous diagrams, and by presenting three separate and independent maps of the world from different aspects —two of them from entirely new ones—with most of the main surface features of the earth, as pointed out by physical geographers, emphasized by lines. These maps have been acknowledged to be well executed, and to serve their purpose, as indeed might have been expected from the work of the first geographical publishing house in London. In this particular enquiry then, it was not facts that were lacking. Whether I made a good use of them or not, may be open to question. A French geologist—M. de Lapparent—thinks I have, and appeals to those physicists who have under their charge the different principles involved in the hypothesis, to point out definitely, wherein I may have failed to properly apply them. †

The present volume is an attempt to elucidate volcanic phenomena by reference to the same explanation of the earth's surface features, and in view of the facts exhibited by Hawaiian volcanoes. The naturalist, Douglas, the first European who looked into the crater of Mokuaweoweo—the summit crater of Mauna

* Comparative Geography, by Carl Ritter, Edinburgh and London, 1865, p. 22.

† "La Symetrie sur le Globe Terrestre," par A. de Lapparent, published in the *Revue des Questions Scientifiques*, January, 1882.

Loa—when in action, said in a letter to a friend on his return, that if he was to attempt to explain the meaning of what he had seen in one word, that word would be—cosmical. The fire-fountains of Mauna Loa, and the vast pile of cooled molten stone—the result of similar eruptions—forming the Hawaiian Group, all solidified from a state of *igneous* fusion, leads every thoughtful observer to the consideration of an earlier stage in the history of our planet,

I ought, perhaps, to say here, in order to prevent misapprehension at the outset, that the theory of volcanic action adopted throughout the following pages, is substantially the same as that advanced by Joseph Prestwich and James D. Dana, the Nestors of British and American geology, respectively, whilst it is also in accord with the general teaching of continental European geologists. The science of vulcanology, however, is specially one of those which is open to reconsideration, modification and improvement, and my object will be attained if the theory, which, as I believe, has been consistently followed throughout, merely serves as a thread on which to string a few valuable pearls of fact. It is perhaps, safe to affirm, that no more compact and complete series of rythmical volcanic eruptions—and those of a typical and fundamental character—have hitherto offered themselves to the study of civilized man in any part of the globe, than those which have occurred during the last sixty-four years on Hawaii.

W. L. GREEN.

Honolulu, November, 1887.

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VESTIGES OF THE MOLTEN GLOBE.

PART II.—THE EARTH'S SURFACE FEATURES AND VOLCANIC PHENOMENA.

CHAPTER I.

INTRODUCTORY.

THE TETRAHEDRAL COLLAPSE OF THE EARTH'S ENVELOPE.

"Of all the re-entering figures, the spherical one is the most simple, since it only depends on a single element, the size of its radius. The natural inclination of the human mind, to attribute that form to bodies which it comprehends with the greatest facility, disposed it to give the earth a spherical form. But the simplicity of nature should not always be measured by that of our conceptions. Infinitely varied in her effects, nature is only simple in her causes, and her economy consists in producing a great number of phenomena, often very complicated, by means of a small number of general laws."—LAPLACE.

When the first part of the "Vestiges of the Molten Globe" was published in 1875, we deemed it necessary in the preface to apologize for taking the ground throughout, that the earth contains at present a molten substratum at least, with a thin solid crust. Since that date, however, the attitude which a large number of physicists and geologists maintain on this question has considerably changed. In 1876 Prof. Sir William Thomson announced at the meeting of the British Association in Glasgow, that the argument for a solid earth deduced from the

phenomena of precession and nutation must be given up, although holding that on other considerations the hypothesis of a thin crust and liquid interior was untenable. *

Since then, astronomers as well as geologists in all quarters have been presenting facts as they came to their notice which are inexplicable except on the hypothesis of a thin crust, and, at least a liquid or highly plastic substratum. Evidence to this effect continues to press in from all sides. Sir George Airy, lately British Astronomer Royal, in considering the results of pendulum experiments, in India and elsewhere, says:

"The form of the earth is not such as would be taken by a solid structure, but such as would be taken by a fluid mass with solids floating upon it." †

The Rev. O. Fisher's book, "Physics of the Earth's Crust," is throughout a sustained argument for the existence of a liquid or plastic substratum and a thin crust.

Capt. C. E. Dutton, of the U. S. Geological Survey, goes so far as to say: "The plasticity of at least a thin shell next below the solid external rocks, has a validity of the highest order. Reasoning or induction scarcely enters into it, it is substantially an observed fact." ‡

May we not say that the whole tenor of dynamical geology as it is taught to-day, is a standing protest against the conclusions of those mathematicians, who first attribute to the materials composing our planet, incredible physical properties, and then, with consummate skill in mathematical analysis, deduce from those assumed properties, a solid earth.

It is perhaps unnecessary to remark, that on the continent of Europe the solid earth theory has never made much progress. A little prejudice has been excited in

* See Appendix on the Rigidity of the Earth, deduced from the height of the tides.

† Observatory—June, 1878, page 48.

‡ American Journal of Science, No. 136, April, 1882, page 288.

English-speaking countries regarding the hypothesis of a thin crust and molten interior of the earth, by calling the idea "sensational." Perhaps it is. What then? So is the idea of our sun in a state of eruption, or of a sudden conflagration on a distant star. What most concerns the geologist or the astronomer in these questions is, whether the ideas are true or probable.

More exact views have also since 1875, become somewhat widely promulgated respecting what we know about the figure of the earth—and which has an important bearing on the question of the nature of its interior—especially in a series of articles by Major J. Herschell, R. E., which appeared in *Nature*, in 1879–80, and which substantially corroborate almost everything that we ventured to suggest in Part I, Chapter VII, regarding the inadequate methods and general theories for obtaining the earth's exact figure. In the course of these articles Major Herschell explains, that a new mode of attack is necessary to ascertain the exact figure of the earth, inasmuch as it is the irregularities—that is, the particular deformation of the spheroid—that it is now of the most importance to ascertain, although a regular elliptic spheroid may have been found, which may fit the real figure of the earth better than any other regular elliptic spheroid would fit it. *

Mons. A. de Lapparent also, has presented the history of the methods used and the results arrived at, regarding the figure of the earth,† in which he refers to the great importance in a geological point of view of considering the deformation of the spheroidal figure; observing that the *mean* figure of the terrestrial spheroid has probably been ascertained as nearly as the available methods will allow, and in the concluding section on this subject, he remarks:

* *Nature*, May the 8th, 1879, April 22d, 1880, April 29th, 1880.

† Traite de Geologie, par A. de Lapparent, ancien Ingenieur au Corps des Mines, Professeur a L'Institut Catholique de Paris, 1883, page 48.

"These facts, as well as others analogous, which it would be possible to cite, show that the geodetic measurements, or the study of the oscillations of the pendulum, may bring to geology a precious help in aiding it to ascertain, not alone the general figure, but the *deformations* of the terrestrial spheroid."

And here we may observe, that it is the particular deformation of the spheroid which we consider to lie at the base of the science of the earth's physiography and of dynamical geology. It was the origin of the ocean depressions and continental upheavals, as well as of the position and direction of the mountain ranges which more exactly define the form of the continents. The direction of mountain ranges and coast lines are intimately connected with that of lines of volcanoes. Thus volcanoes are brought into direct relation with the figure of the earth, or with the deformation of the spheroid, and in order to understand more readily what follows, it may be well to place before the reader a short *resume* of the hypothesis propounded in the first part of "The Vestiges of the Molten Globe," regarding the figure of the earth, in which we endeavor to show that the regular solid which may be said to represent the earth's collapse, or modification of the spheroidal figure, is the tetrahedron.

We cannot do this better than by offering a translation of the summary of the theory which is presented in the *Traite de Geologie* of M. de Lapparent. He says: *

"TETRAHEDRAL SYSTEM.

"*Principle of the system. Tetrahedron. Hexatetrahedron.*—The criticisms which have just been formulated against the application to the terrestrial globe of the pentagonal symmetry, do not apply to the *tetrahedral symmetry* developed by Mr. Lowthian Green. Amongst the regular polyhedrons which may be inscribed in a sphere, Elie de Beaumont had pointed out the *tetrahedron* (Fig. 606)

* Paris, 1883, page 1245.

formed by the reunion of six grand circles cutting each other, three to three, at angles of 120 degrees. It has seemed to Mr. Green that this solid of an order of symmetry less elevated, explains better the general features of the terrestrial surface, and allows them all to be grouped around one single formula, seductive by its simplicity.

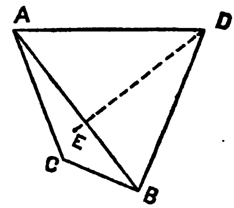

FIGURE 606.

"And first it is proper to justify the assimilation, in appearance very paradoxical, of the nearly spherical figure of the globe with that of a tetrahedron. To this end, instead of considering the tetrahedron properly so-called, it will suffice to substitute for it one of the solids which is derived naturally from it in crystalography, and which is called the *hexatetrahedron* (Fig. 607.) It is obtained by substituting, at each of the equilateral triangles of the preceding figure, a hexagon, A.D., D.B., B.A., and causing to depart from it, from an exterior point S., a pyramid of six faces, having for its base the hexagon in question. It is easy to arrange it in such a manner that the twenty-four-faced solid, thus obtained, may be inscribed in the sphere, from which it departs much less than the tetrahedron from which it is derived. Let us now suppose that at each of the angles of this new solid we substitute curved lines which will render the faces convex (Fig. 608.) In this case (frequently realized by diamond crystals) we may approach as near as we wish to the spherical figure. We may say then, with regard to the condition of having in view the hexatetrahedron with curved faces, nothing is less contradictory in itself than the attribution to the solid

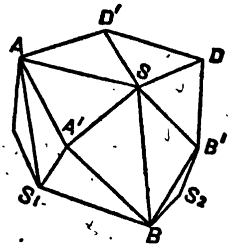

FIGURE 607.

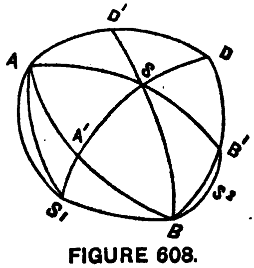

FIGURE 608.

portion of the globe of a tetrahedral symmetry.

"*Physical Arguments.*—This geometrical justification being accepted, it suffices to show that the tetrahedral figure is *physically* admissible for a spherical shell which collapses by reason of the contraction of its support. Mr. Green has thought that in considering a sphere as formed by the juxta-position of an infinite number of cylindrical rings of decreasing diameter, we may avail ourselves of the experiments of Fairbairn, on the collapse of tubes of circular section. It appears that generally, the section of the tubes tends to take, under the influence of the force exerted, the form of an equilateral triangle with concave sides (Fig. 609). Hence it seems admissible that the collapse of a spherical shell may give birth to that which, for a spheroid, is the equivalent of the equilateral triangle, that is to say, a tetrahedral form. Mr. Green has also

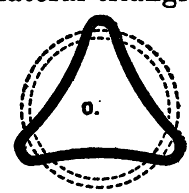

FIGURE 609.

observed that such is nearly the figure which a bubble of gas takes whilst rising in water, and the same result would have been obtained in the experiments made in collapsing with the desired precautions, little balloons of india-rubber.[1] We may remark further, that whilst the sphere is, of all the regular solids, that which embraces the greatest volume under the least surface, the tetrahedron is, on the contrary, that in which the proportion of surface to volume is a maximum. It is in consequence quite natural that a spherical shell, imperfectly sustained, should seek to take the tetrahedral figure, destined to ensure for it the preservation of its superficies the longest possible time.

"*Geographical consequences of the tetrahedral form:*—These points established, let us return, for the sake of simplicity, to the ordinary tetrahedron, and let us admit that,

(1.) This result with the remark which follows, has been communicated to the author by M. Lallemand, Engineer of Mines.

in consequence of movements induced by its collapse, the solid crust has to-day the form of a regular tetrahedron, A.B.C.D., (Fig. 610), turning round one of its principal axes, D.E., whilst the oceanic mass is represented by a sphere slightly bulged at the equator and having for its centre the centre of gravity of the pyramid.

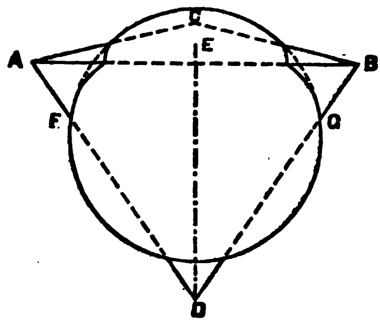

FIGURE 610.

"Under these conditions, there would exist, in the Northern Hemisphere, three symmetrical continental projections, while the Arctic Pole would be the centre of the sea; on the other hand, a continental protuberance will appear at the Antarctic Pole. And the northern continents, terminating in points, towards the south, as well as in the direction of the east, and of west, will leave oceans between them largely developed in the Southern Hemisphere and terminating towards the north, *en cul-de-sac*. But if we refer to the considerations expressed in the first part of this work, we shall find that such is exactly in a general view, the disposition of the continental masses and of the oceans over the globe, on condition that we join together Africa and Europe, and restore between this latter and Asia, the separation which formerly existed, when, along the Siberian depression, the glacial sea could communicate with the Caspian.

"*Torsion of the terrestrial tetrahedron:*—It is true that, so far, two things remain unexplained; on the one hand, the separation of all the continents into two masses by the great Mediterranean depression, on the other hand, the singular deviation towards the east, which the southern part of the continents suffer. Thus South America, is almost entirely to the east of North America. South

Africa is not less diverted, and Australia, considered as the southern prolongation of the Asiatic continent evidently only occupies the eastern portion. But it is precisely the merit of Mr. Green's system to have been able to make these apparent anomalies, enter into the plan of the tetrahedral symmetry.

"Indeed it must not be forgotten that the terrestrial tetrahedron is animated by a movement of rotation around the polar axis. At first, when the effects of the collapse had not yet become sensible, the different points of the spheroid had concordant velocities. But as soon as the four protuberances, A.B.C.D., commenced to become accentuated, the three first, departing from the axis of rotation, D.E., have only been able to retain an insufficient velocity, considering their new distance from the axis. The zone of the spheroid which contains them is therefore found *en retard*, relatively to the equatorial zone, and has been in consequence, solicited to a deviation contrary to the movement. The opposite was the case with the regions nearer the southern point, D. In proportion as the collapse caused them to approach the axis, D,E., it caused them to exhibit an excess of velocity, with a tendency to the deviation of the southern zone towards the east. Thus the terrestrial hexatetrahedron has been submitted to a veritable *torsion*, which has produced, between its northern and southern part, a line of continuous rupture, and this line has constituted a new zone of depression to be added to those which mark the three oceanic masses, the Pacific, Atlantic and Indian oceans.

"*Diverse consequences:*—With regard to the absolute position of this line, which is not parallel to the terrestrial equator, Mr. Green has sought to justify it by astronomical considerations, in making intervene the tides produced at first, in the fluid interior mass, by the combined action of the sun and moon, when the crust was still

thin enough to obey an action of this nature. The author goes further and endeavors to attribute to the same cause the inclination of the terrestrial axis upon the plane of the ecliptic. Observing that the three northern protuberances are of the same order as the equatorial bulge, to which is due the procession of the equinoxes, he has concluded that the inclination of the ecliptic had for its cause the excess of the luni-solar attraction upon these three protuberances ; and analogous considerations to those which have been indicated, have induced him to calculate for the amount of this inclination, a cipher nearly identical with that ascertained by astronomers.

"*Resume of the hypothesis:*—In leaving to Mr. Green the responsibility of these latter reconciliations, which raise very delicate questions of mechanics and astronomy, we think that the geographical coincidences noted above may suffice to impress upon the tetrahedral hypothesis a high degree of probability. Without doubt this hypothesis, only embraces the grand features of the terrestrial surface, and does not yet give the key of the details, as the *reseau* pentagonal pretended to do. However, Mr. Green has indicated the predominance, in the region of the Pacific of several systems of directions which agree sufficiently well with the lines of a tetrahedral symmetry, or *reseau ter naire*, and this analysis may be pushed further hereafter. However this may be, it is already a considerable result, to have grouped around one very simple idea, the fundamental data of the geography of our globe. One thing adds still, in our eyes, to the merit of this hypothesis ; which is that it connects the development of the terrestrial relief to a single plan, of which the grand lines have been designed from the commencement. Geology has taught us that the plan of the continental masses was everywhere of very ancient date, and that, generally, the solid land was formed by successive additions of sedimentary beds around crystalline

nuclei, which first emerged. Very rarely has the regularity of this increase been interrupted by great changes supervening in the reciprocal domain of the land and the waters. But nothing is in better accord with the idea of a tetrahedral symmetry which, marked out from the first by the phenomenon of collapse, would only become accentuated thereafter, without there having been either great changes of the terrestrial axis, or extraordinary cataclysms to which fancy has too often had recourse.

"We will finish by noting the possibility of explaining, by the tetrahedral constitution of the globe, one of the peculiarities of the distribution of gravity on its surface. We have said that, in spite of the excess of attraction which it would seem that the continental masses ought to exercise upon the pendulum, this latter shows rather an excess of gravity over the great open oceans. But if we admit the tetrahedral form, it is not surprising that the sea should be attracted by the three northern protuberances, whilst its surface would tend to flatten in the middle of each of the oceanic depressions. The surface of these depressions would then be nearer to the centre of the earth, which would explain the excess of attraction observed."

Not only has M. De Lapparent taken the pains to understand thoroughly, every essential point of the tetrahedral collapse theory as we presented it, but he has, at the suggestion of M. Lallemand, Ingenieur des Mines, supplemented it, just where we had left it somewhat in default; that is, in showing the definite mathematical and physical connection between the form of a collapsing spherical crust and the tetrahedral figure, by referring to the fact that whilst the sphere is of all the regular solids, that which embraces the greatest volume with the smallest surface, the tetrahedron, is on the contrary, that in which the proportion of surface to volume is a maximum.

A collapsing spherical envelope then, tends to approach that regular figure which gives the most relief to the tangential strains with the least amount of movement or action; or—presented in another way—tends to adopt that form which most quickly and permanently disposes of the excess of its linear dimensions about the diminishing volume of the contents which support it.* It seems unnecessary to add that the uniform collapsing force, in the case of the earth's crust; is simply its weight.

* See Appendix. On the forms assumed by collapsing envelopes, and their bearing on the figure of the earth. Carl Ritter on the deformation of the spheroid. Connection with dynamical geology. The uniformity of nature.

CHAPTER II.

THE EARTH'S FORM IS ITS HISTORY.

"The delineation of the principal characteristics of telluric phenomena must begin with the form of our planet and its relations in space. Here too, we may say, that it is not only the mineralogical character of rocks, whether they are crystalline, granular, or densely fossiliferous, but the geometrical form of the earth itself, which indicates the mode of its origin, and is, in fact, its history."—ALEXANDER VON HUMBOLDT. *

Amidst the results, somewhat discordant, which the attempt to determine the exact figure of the earth has brought forth, two great facts are prominent, and now universally admitted: first, that the figure is in a general sense approximately a spheroid of revolution—and second, that great irregularities exist in that figure. The first fact points to the earliest period in the history of the globe, as the effect of rotation on a molten mass; whilst the second fact—the deformation of the spheroid—has been attributed to secular refrigeration, and must have been constantly, and up to the present hour in progress. †

One deformation of the spheroid which some of the physicists who have this important question under consideration, believe to be strongly indicated by observation, is towards an ellipsoid with three unequal axes; or in other words, they assume that the spheroid of revo-

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* Cosmos: by Alexander von Humboldt, Vol. 2, p. 163. New York. Translated by E. C. Utte.

† See Appendix. On some objections which have been urged against the hypothesis of the earth's contraction by loss of heat, as the cause of the irregularity of the surface.

lution has been slightly compressed at the equator, and equally at two opposite sides, thus giving to the section of the earth through the equator a slightly oval form.

It seems probable, indeed, on general considerations, and on Elie de Beaumont's recognized principle of the molten interior of the earth tending to contract more rapidly than the cool and solidified crust, that some slight change of figure would be the easiest method by which the earth's spheroidal envelope might early tend to accommodate itself to the shrinking nucleus. It is a mathematical certainty that the slightest deviation of the equator of the spheroidal crust from a circular figure would reduce the contained capacity, and might enable the crust still to embrace its internal mass exactly, notwithstanding the diminution of the nucleus and the permanence of the linear dimensions of the crust.*

Elie de Beaumont, however, who clearly taught these important principles, did not overlook the limit to such a method of accommodation between the earth's solid crust and its contracting molten interior, "in the immense forces which tend to preserve the planet spheroidal."

Jacobi claims to have shown, and mathematicians generally have accepted the conclusion, that within certain limits, the figure of an ellipsoid with three unequal axes,

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* Elie de Beaumont, (Notice sur les Systemes des Montagnes, page 1278, observes: "We have supposed, as is usually done, that the surface of the tranquil waters is a regular spheroid, that is to say *an ellipsoid of revolution;* but everybody knows that this is a simple approximation. We do not know two meridians equal to each other. Not one of them is a regular ellipse, and not one of the parallels of latitude is a perfect circle. The equator itself is not rigorously a circle." At page 1279 he explains that these grand curvatures, *bossellements*, of the earth's crust *to which are due the general configuration of continents and seas*, may exist at first, without crushing the strata, and at page 1237, that "in view of the smallness of the curve and the indefinite number of its fissures, it seems to me impossible that it (the earth's crust) could ever have sustained itself without support." In fine, that the first effect of the contraction of the interior mass was a slight deformation of the spheroid as a whole, and which deformation defined the situation of the great oceanic and continental areas.

of which the least is the axis of rotation, may be a form of equilibrium for a liquid rotating mass; so that within certain limits—as Beaumont suggested might be the case —neither the earth's rotation, nor tangential strains in the crust, and the resulting crushing, need necessarily prevent the adoption of a figure for the earth, not truly spheroidal, which the diminution of the nucleus relatively to the crust resting upon it would tend to produce.

Thomson and Tait, however, say: * "No one seems yet to have attempted to solve the general problem of finding all the forms of equilibrium which a mass of homogeneous incompressible fluid, rotating with uniform angular velocity may assume." The important point for the consideration of the geologist, in the meantime, is, that there may be other forms of equilibrium for the earth's fluid surface, and of the crust which rests upon it, besides that of a spheroid of revolution or of an ellipsoid with three unequal axes; so that in considering the grand curvatures of the earth's figure, such for instance as will embrace a third or a fourth of the spheroid, and would include the great oceanic and continental flexures, we need not perhaps, trouble ourselves with the supposed difficulty that such an arch or dome would not be able to support itself, from its inherent weakness. As Beaumont explained, it does not support itself, but the molten interior supports it, and mathematicians tell us how this may be possible, inasmuch as certain great symmetrical curves on the surface of the fluid ellipsoid, and yet not truly spheroidal ones, may be forms of equilibrium. The principle of the arch or dome, does not apply until certain limits of curvature are passed.

There exist, therefore, in the secular refrigeration of the earth, two constantly acting and constantly opposing forces—the effort of the crust, and the contracting

* Elements of Natural Philosophy, Oxford, 1873. Page 275, paragraph 719.

nucleus, to adapt themselves to each other by deforming the spheroid, and that of rotation, to maintain the spheroidal figure more nearly exact. The effects become complicated when certain assignable limits are about to be passed—with the crushing, corrugating, faulting, and upheaval of portions of the crust, as well as by the injection of the molten interior into the fissures formed in it by the contending forces, as one or the other prevails.

The actual deformation of the contracting spheroid may be called its normal figure, and the moment this deformation has exceeded certain limits—and which excess the constant internal cooling continually tends to produce—a new order of mechanical effects comes into play, which results in a fresh set of phenomena, instead of a further change of figure.

We thus perceive the intimate relation which may exist between the figure of the earth and volcanic phenomena, and how true and even literal may be the aphorism that "the earth's form is its history." But we cannot perhaps, better illustrate the theory of Elie de Beaumont, the foremost telluric engineer of his age, than by a few extracts from the writings of one of the most philosophical observers of natural phenomena the world ever saw.

Charles Darwin,. whilst contemplating certain great volcanic events on the west coast of South America, became impressed, like Humboldt and Beaumont, with the necessity of including in the term volcanic action, the force by which mountain chains and continents are elevated—the force, in fine, by which the spheroid becomes deformed. Earthquakes, the sudden uplift of the whole Chilean coast, and probably of the whole Chilean Cordillera, together with the simultaneous appearance of volcanic action, at remote points in that chain, led him to say: *

* On the connection of certain Volcanic Phenomena in South Amer-

"When first considering these phenomena, which prove that an actual movement in the subterranean volcanic matter occurred almost at the same instant of time at very distant places, the idea of water splashing up through holes in the ice of a frozen pool, when a person stamps on the surface, came irresistibly before my mind. The inference from it was obvious, namely, that the land in Chile floated on a lake of molten stone, of which the area, as known from the various points in eruption on the day of the earthquake would be nearly double that of the Black Sea. If this inference be denied, the only alternative is, that channels from the various points of eruption unite in some deep seated focus, like the arteries of the body in the heart, whence an impulse can be transmitted to distant parts of the surface with nearly equal force. But according to this view, if two separate trains of volcanoes in the Andes have any connection whatever, which seems highly probable, from the symmetry of the Cordillera, (and possibly an intimate one as will presently be discussed) then the common focus from which the two main branches are sent off, must be seated at an enormous depth. But all the calculations regarding the depth at which molten rocks must necessarily be met with, if they can be at all trusted, tend to prove, that the earth's crust is not much more, and perhaps less, than twenty miles in thickness; and if this be so, the crust may indeed be well compared to a thin sheet of ice over a frozen pool.

"These considerations are, perhaps, of little weight, but we must bear in mind, that the elevation of many hundred square miles of territory near Concepcion is part of the same phenomenon, with that splashing up, if I may so call it, of volcanic matter through the orifices of the Cordillera at the moment of the shock; and as this eleva-

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ica; and on the Formation of Mountain Chains and Volcanoes, as the effect of the same power by which continents are elevated. By Charles Darwin, Esq., Sec'y G.S., F.R.S. Paper read March 7th, 1838.

tion is only one of a long series, by which the whole coast of Chile and Peru, even, for more than a thousand miles, has been upraised several hundred feet, within the recent period, (as I endeavored to show in a paper formally read to the Society, and I hope hereafter to prove more fully) the body of matter added below must have been enormous. When we reflect on this, it is obvious that the term *channel* cannot be applied to a means of communication extending beneath a large portion of a continent, and from the interior of the globe to the superficial crust. The facts appear to me clearly to indicate some slow, but in its effects, great change in the form of the surface of the fluid on which the land rests. In a geological point of view, it is of the highest importance thus to find three great phenomena—a submarine outburst, a period of renewed activity through many habitual vents, and a permanent elevation of the land,—forming parts of one action, and being the effects of one great cause, modified only by local circumstances. When we consider that the southern volcanoes were in eruption some days before the earthquake, and that one of them, Minchinmadon, has seldom been dormant for the last thirty years, and that they all remained active for many months afterwards, we must conclude that the impulse given to them at that moment, was of the same nature with the force which has kept up their activity during the many ages necessary to accumulate the volcanic matter into great snow-clad cones, and which force still continues to add to their height. If the earthquake or trembling of the ground, (which, however we have seen was less near these volcanoes than elsewhere) had acted in no other way than in merely breaking the crust over the lava within the craters, a few jets of smoke might have been emitted, but it could not have given rise to a prolonged and vigorous period of activity.

"But the power which manifested itself in this renewed action, and to which same power, acting at former periods, the entire formation of these several volcanoes has evidently been due, was likewise the cause of the permanent elevation of the land;—a power, I may remark, which acts in paroxysmal upheavals like that at Concepcion, and in great volcanic eruptions in precisely the same manner, for both these phenomena occur only after long intervals of rest, during which the volcano merely casts out, perhaps, a few showers of scoriæ, and the land rises with so slow a movement, that it is called insensible;—therefore no theory of the cause of volcanoes which is not applicable to continental elevations can be considered well-grounded. Those who believe that volcanoes are caused by the percolation of water to the metallic bases of the earth, or simply to intensely heated rock, must be prepared either to give up this view or to extend it to the elevation of such vast continents as that of South America."

It seems fortunate for the sake of scientific truth, that so philosophic an observer of nature as Darwin should have been an eye-witness of the great South American catastrophe of 1835, and that he should have taken pains to describe it; otherwise the whole phenomena might have passed with no other record than that of ignorant observers, or the almost equally valueless notice of mere pedagogues. Geological catastrophes of this character, and on so grand a scale, may only occur once in centuries. Catastrophes, however, which are parts of a regular sequence of events, and which differ from the fall of a pebble into the stream, as the bank wears away, only by their magnitude.

It perhaps adds to the value of Darwin's observations that he had no special theory to offer as to the primary cause of the grand phenomena which he describes, and that he was not prepared to admit, that secular refriger-

ation, alone was sufficient to account for all the varied phases of volcanic action. This invaluable paper concludes with the following paragraph:

"The secular shrinking of the earth's crust* has been considered by many geologists a sufficient cause to account for the primary motive power of these subterranean disturbances; but how it can explain the slow *elevation*, not only of linear spaces, but of great continents, I cannot understand. With the same view some highly important speculations have recently been advanced—such as changes of pressure on the internal fluid mass, from the deposition of fresh sedimentary beds, and even the attraction of the planetary bodies on a sphere not solid throughout; but we can see that there must be many agents, modifying all such primary powers; and the furthest generalization which the consideration of the volcanic phenomena described in this paper appears to lead to, is, that the configuration of the fluid surface of the earth's nucleus is subject to some change—its cause completely unknown—its action slow, intermittent, but irresistible."†

Now let us keep well in mind Darwin's interpretation of the phenomena he observed in South America. A vast area of the earth's thin solidified crust appeared to

* The expression "secular shrinking of the earth's crust" has been constantly used by some of the best English and American geologists to define the results of secular refrigeration. As the crust of the earth does crush and fold and fault by the contraction of the nucleus, it may in that sense be said to shrink or contract, but we venture to think that this mode of expression is equivocal to say the least. Elie de Beaumont never expressed himself in this way. It is the molten nucleus or substratum which shrinks or contracts, and the crust crushes, folds or faults down upon it. The crust indeed may, and probably does, expand, from the effects of hydrothermal metamorphism, as we elsewhere explain. The fact that the nucleus or substratum, after a certain early stage of the cooling, shrinks or contracts more rapidly than the crust, is the basis of the whole science of dynamical geology, as set forth by Elie de Beaumont and his followers. For this reason we think that the term "shrinking and contraction of the earth's crust" as used by some of the best English geologists is equivocal, and should be avoided. W. L. G.

† *Ibid*, p. 631.

have been stamped upon or pressed upon, and the molten stratum on which it rested was forced out simultaneously at openings in distant points of the Andes, while the whole area was at the same moment suddenly jerked up. In fine, he described a vast hydrostatic phenomenon—a change in the configuration of the fluid surface of the earth's nucleus—which he is careful to separate from the ejection of "a few showers of scoriæ."

Then let us turn to Elie de Beaumont's own account of his theory of the thin crust of the earth supported on a molten contracting nucleus, both changing their shapes, to allow of the mutual accommodation of their relatively altering dimensions; but such deformation opposed and limited by the earth's rotation. Let us at the same time bear in mind that on the principle advanced by Jacobi, certain grand primary oceanic and continental flexures, not truly spheroidal, may, within certain limits, exist in the fluid nucleus as surfaces of equilibrium, notwithstanding the earth's rotation. Beaumont says:

"Its weight (that of the crust) is kept constantly maintained by the liquid interior. This liquid interior not being any longer able to fill up and sustain the crust everywhere, if the latter preserved its regular spheroidal figure which corresponds to a *maximum of capacity*, it (the crust) departs from that figure by slightly flexing; but such a flexure could not take place without certain portions of the envelope suffering compression, and others an extension; without the different columns of the liquid interior mass changing their respective lengths; and without the immense forces which tend to preserve the planet spheroidal, causing them to depart from a state of equilibrium. So long as the deformation remained excessively small, the resistance of the solid crust has been able to counteract all these causes of rupture or crushing. But as these causes

become necessarily more and more intense, in proportion as the deformation becomes greater and greater by the progress of the refrigeration, a *debacle* at last becomes inevitable. The tendency of the entire mass to return to a figure nearer spheroidal has given birth to a system of forces gradually increasing which have ended by forcing the crust to diminish its inconvenient amplitude by the sudden formation of a sort of fold."*

Could the theory of one philosopher be better illustrated by the observation of another than by the way in which this concise summary by Beaumont of the theoretical results of secular refrigeration, has been illustrated by Darwin's observations on the volcanic events in Chile in 1835? Darwin has in this paper erected a lasting altar to the unknown mechanical power which exists as a prime mover in volcanic phenomena, including the formation of mountains and the elevation of continents; but this unknown power, referred to indeed by him as "some change in the configuration of the fluid surface of the earth's nucleus," seems to have been more definitely indicated by the great apostle of the principle of secular refrigeration—Elie de Beaumont—as the struggle between the deformation of the spheroid, by loss of internal heat and volume, and the earth's rotation, which as constantly tends to cause it to revert to the true spheroidal figure.

It is true that Darwin's paper, just quoted, seems to have been written partly to exhibit "certain inferences regarding the slow formation of mountain chains," and this has been sometimes held to be opposed to Beaumont's theory. But Beaumont's great principle of the gradually accumulating forces under the slow influence of secular refrigeration ending in a *debacle* and sudden uplift, seems to be beautifully illustrated by Darwin's

* Notice sur les Systemes de Montagnes. Par Elie de Beaumont, Paris, 1852, page 1238.

observations. Beaumont nowhere intimates that mountain chains are raised in a day, although mountain ranges, and those of the American Cordillera in particular, seem often to have been elevated, geologically speaking, with comparative rapidity. Dr. A. Geike, referring to the Rocky Mountain region, says:

"These examples show that the elevation of mountains, like that of continents, has been occasional, and, so to speak, paroxysmal, long intervals elapsed when a slow subsidence took place, but at last a point was reached when the descending crust, unable any longer to withstand the accumulated lateral pressure, was forced to find relief by rising into mountain ridges."*

It is satisfactory to find so prominent a British geologist thus far sustaining Beaumont's philosophical views of mountain-making, by reference to practical examples —thanks to the splendid work of the American geologists on their grand continent. Just how much a mountain range has ever been raised at one lift we have no means of deciding; but when we find, in our short experience, that Chile and its Cordillera can be jerked up several feet at one stroke, we may well be careful how we limit the magnitude of such catastrophes in all past time.

These volcanic displays on the west coast of America are grand typical phenomena, still constantly in action. The Andes have been called a mountain system "in process of formation." The subsidence of the bed of the Pacific, and the resulting upheaval of the Cordillera is one of a set of similar phenomena, exhibited in the three great oceans—the Pacific, the Atlantic and the Indian. By including in our view the Arctic ocean we have the four grand areas of depression, or oceanic, but continent-forming flexures of the earth's crust, the foci of which were originally equidistant over the spheroid

* Text Book of Geology by Archibald Geike, London, 1882, page 919.

and symmetrical—as any such deformation of the earth's figure must be, or must tend to become—with the earth's axis of rotation.

These four grand oceanic flexures, viewed in connection with the properties of the tetrahedron, indicate in the clearest manner what has been the geometrical character of the slight deformation of the earth's spheroidal figure which has been primarily produced in order that the earth's crust should continue to embrace exactly the contracting nucleus.

The originally symmetrical relations of these four grand depressions of the earth's crust, and the resulting continental swells, have been somewhat deranged, as we observe when we contemplate the map of the world. The Pacific depression has usurped more than its share of the collapsing spheroid, and this excessive oceanic flexure seems not only to have raised the lofty pile of the Andes to the eastward of it, but to have pushed South America eastward also into the Atlantic, and nearer to Africa.*

If now we turn to the northern hemisphere we observe that Asia appears to be crowded, apparently by the same excessive Pacific depression, in the opposite direction on to Europe and Africa, so that the northern branch of the Indian ocean now shown in the Uralo-Caspian depression, which once corresponded with the northern basins of the Pacific and of the Atlantic, has been obliterated. The continents have to a great extent been thus thrown together, so that to-day geographers often exhibit the globe in two hemispheres, in one of which is nearly all the land, and in the other nearly all the water—the familiar map, in fine, of the land and water hemispheres.

* Some of these phenomena have been somewhat fully referred to in Part I., and by Mons. de Lapparent as quoted in Chapter I., but a further striking peculiarity of the earth's surface features, the land and water hemispheres, has not yet been specially referred to as an ultimate result of the tetrahedral collapse.

The land appears to have accumulated around, or closed in upon, Africa, which seems to have served as a fulcrum or stationary axis against which some great mechanical power has acted. A force which has had the effect, during past ages, of making a point in the English Channel—the gateway to the port of London, and to the principal ports of Europe—the centre of the land hemisphere, and the centre therefore of the habitable portion of the globe.

It has been observed by Dana that the American continent has its main and highest ranges of mountains on the western side. R. Mallet,* referring to this fact, called attention to what seems inevitable, that on the hypothesis of a depression of the thin floating crust over a great ocean bed at any considerable distance from the poles, this is a necessary result, inasmuch as the eastwardly rotation of the earth would, as the crust subsided, or approached the axis of rotation, tend to preserve the velocity it had in the higher position, and therefore press to the eastward or against the western side of the continent, and thus tend to raise it highest on that side. But three great subsiding ocean beds, mainly in middle latitudes in the southern hemisphere,

* Volcanic Energy: Phil. Trans. of the Royal Society, Vol. 163, Part I., page 162.

It seems worth noting that in this paper Mallet refers to the probable early deformation of the earth's thin, flexible crust, as it accommodated itself to the contracting molten nucleus "which hollowed out the ocean bed to very much the general outlines that we now see, and so assigned the general form of the continents." This general theory, so far, is the same as that of Elie de Beaumont, and which we follow. The excessively thickened crust which Mr. Mallet considered it necessary to assume had supervened—since the continents and oceans were roughly blocked out—and even since the mesozoic era, seems difficult to understand, whilst it fails, as we believe, to be reconcilable with volcanic and physiographic phenomena. This very great thickening of the solidified crust, indeed, which is supposed to have occurred during known geological periods, almost seems invented to give an opportunity for devising machinery to melt it again, and to get the matter so melted to the earth's surface, but which machinery would be quite unnecessary if he had left the earth's crust thin—as he first found it.

all pushing to the eastward, would tend not only to throw up ridges on the western side of the continents (as Mallet admits), but must have tended also to move the whole southern floating crust to the eastward.*

The three southern ocean depressions—that is, having their foci many degrees to the southward of the equator—acting in conjunction with the fourth, or Arctic ocean depression, with its focus at the North Pole, tends to throw up the crust of the earth in middle latitudes in the northern hemisphere, as indeed it shows itself to be so thrown up. This upheaval again produces a retardation of the rotation of the floating crust in the northern hemisphere, or in other words, to make it appear relatively pushed to the westward.

Thus actuated by two forces in opposite directions, a shearing strain has been set up between the crusts of the northern and southern hemispheres, they have yielded to that strain along the great volcanic "zone of fracture" already formed in a plane parallel to the ecliptic, and to the direction of the movement of the crest of the internal luni-solar tide-wave. By the movement of the earth's crust along it in opposite directions, South America has been nearly separated from its northern half-continent, and has been pushed towards Africa. Asia on the other hand, being in middle latitudes of the northern hemisphere—and therefore on a

* If the force which jerked up the Chilean Cordillera bodily several feet in 1835 came from the Pacific, the same force must have tended to push, and perhaps did at that moment push, the Chilean coast some feet to the eastward. But who could detect that movement unless, indeed, it is shown in the retreat of the sea—which at Concepcion was, as it usually is, the first result of these great earthquakes—followed by its immediate return in a vast wave? The liquid ocean could not have been suddenly pushed with the solid land, but must have been momentarily left behind. Inasmuch, however, as the advance of a great wave from the ocean, however formed, might first show its effects in the recession of the water from the shore, nothing decisive as to the movement of the land is to be gathered from the retreat of the water, although it is clear that this would be a first result of the push of this part of the continent to the eastward.

relatively upheaved portion of that hemisphere—has, by the opposite action of retarded rotation, been crowded to the westward, and on to Europe and Africa. The latter half-continent with the line of fracture far to the northward, but still belonging to the southern system, thus became the most massive of the southern half-continents, while from its more northerly or intermediate position it has been retained more nearly in its original place by the two forces acting in opposite directions—Africa is the great grounded floe, against which the ice drifting in the neighborhood, jams.

The comparatively narrow space between the fracture to the north of Africa and the polar region of depression, where the retarding effect of upheaval (or westwardly drift of the floating crust) is reduced to a minimum, or perhaps reversed, has been too small to allow Europe and Asia, like a great floating iceberg, to drift through. The grand ridges, plateaus, and mountain chains of Asia, therefore, as depicted on any good map, exhibit not only how the great elevated central plateau of that continent has been upheaved between the three oceanic depressions—the Pacific, Indian and Arctic; but also exhibit how it has become blocked against Africa, showing the bending of the great ridges as they approach Arabia (geographically belonging to the African continent), and appearing like the ridging of a retarded glacier, or of an ice-gorge in a frozen river.

Australia has been thrown, both by Asia leaving it and travelling westward, and by the eastward push of the subsiding bed of the Indian ocean, out by itself into the Pacific and into the water hemisphere. Thus, anomalous in everything, it alone of all the continental divisions, retained the flora and fauna of a former age, separated as it early became, from all the rest.

The simple postulate that the earth's solid crust and contracting molten interior may have primarily accom-

modated their differing dimensions by approaching that regular figure which admits the largest amount of solid crust to the least cubic content—that is towards the tetrahedron—not only seems to account, under the influence of the earth's rotation, for the main features of the earth's surface, as more particularly described in Part I, but also for the land and water hemispheres, which at first sight, seem incompatible with the assumed tetrahedral deformation of the spheroid.*

The earth is not yet, however, a dead planet, like the moon. † On the contrary, all its features, the form of its oceans and continents, the direction of its mountain ranges, and of its great bands of active volcanoes indicate life and motion. Not a motion truly, that can at every moment be detected, but these features all show it, just as the configuration of the "fixed" stars and of the nebulæ in the heavens indicate that all is there in movement. This movement of the earth's crust, is in the broad sense, volcanic action, and it is an action which has left its own record.

The principles which have been appealed to for producing the earth's great surface features, are also prominently indicated in volcanic action properly so-called. Or, as Beaumont expresses it, in the change in the respective lengths of the columns of the internal fluid mass, resulting from the two opposing actions of collapse and rotation; and we are constrained to acknowledge with Darwin, that in all past time, and up to the present

*Professor J. D. Dana, "On the Evolution of the Earth's Fundamental Features." See Appendix.

† The accumulation of the continents around Africa, may ultimately bring the earth to the condition of the moon, which has its prolate face constantly pointed to the earth ; and to the time when the pyramids of Egypt—perhaps as buried fossils—may constantly point to our satellite; and when the length of the day will therefore, coincide with the period of its revolution round the earth; the projecting side of our planet being brought "like a pendulum to the vertical," by the attraction of the moon upon it, whilst under the influence of tidal friction.

hour, "the configuration of the fluid surface of the earth's nucleus has been subject to some change," * * "its action slow, intermittent, but irresistible," whilst the grand features of the earth's solid surface—clearly pointing to a disarrangement of an originally symmetrical disposition of them—exhibit themselves not only as the direct effects of the secular refrigeration of that nucleus, but as also modified by rotation, or, in the language of Beaumont, "by the immense forces which tend to preserve the planet spheroidal."

In thus reviewing the special modifications which the earth's surface features have suffered from the collapse of the crust, as the planet has through the ages continued to spin "down the ringing grooves of change," we are led to appreciate to the fullest extent the remark of Alexander von Humboldt, that "the geometrical form of the earth itself indicates the mode of its origin, and is, in fact, its history."

We shall see in the next chapter, that along the main grooves formed once and forever in the earth's crust, by combined internal and external, or astronomical causes, the main exhibitions of volcanic action appear; and that volcanoes so far indicate their nature by their distribution, that they cannot be regarded as local and accidental features, but must be contemplated together as a grand cosmical phenomenon.

CHAPTER III.

THE DISTRIBUTION OF VOLCANOES.

"Les volcans se sont souvent alignes suivant des fractures paralleles a des chaines des montagnes, et que devaient probablement a l'elevation des ces chaines leur premiere origin; mais cela no conduit nullement a considerer les chaines elles-memes, come etant dues a ce jeu prolonge des events volcaniques, anquel s'applique proprement le sens de l'expresion action volcaniques."—ELIE DE BEAUMONT.

With regard to the facts of the distribution of volcanoes, it will perhaps, be more satisfactory to commence this chapter with the exact words of an acknowledged authority on physical geography, rather than with our own account of how volcanoes are distributed over the surface of the earth, especially as the description is found in a text-book for educational purposes, and disconnected from any special theory as to the cause of that particular distribution.

The account of the late Arnold Guyot, formerly of Neufchatel, and afterwards Professor of Physical Geography and Geology, College of New Jersey, will probably be accepted as a fair and able, at the same time simple and succinct method, of presenting the facts of the distribution of volcanoes as they exist. He says: *

"2. *General Distribution of Volcanoes:*—Nearly all of the volcanoes of the earth's surface are situated along the mountain ranges and belts of islands which skirt the shores of the continents, while the interior is almost destitute of them. Omitting a few extinct craters, the only well authenticated exception to this rule is found

* Physical Geography, by Arnold Guyot, New York. Scribner, Armstrong & Co. (No date). Preface dated April 25, 1873.

in the few volcanoes around the Thian-shan mountains, in the heart of the great Asiatic continent, nearly 2,000 miles from the sea.

"II. VOLCANIC ZONES.

"1. *Two Great Terrestrial Zones*, include nearly all the known volcanoes of the globe, arranged in long bands or series, or in isolated groups.

"The *first zone* includes the vast array of mountain chains, peninsulas and bands of islands which encircle the Pacific Ocean with a belt of burning mountains. Within it occur in the New World, (1) the Andes mountains, with three of the most remarkable series of volcanoes—those of Chile, Bolivia, and Ecuador—separated by hundreds of miles; (2) the volcanic group of Central America; (3) the series of Mexico; (4) the series of the Sierra Nevada and Cascade mountains; (5) the group of Alaska, and (6) the long series of the Aleutian Islands.

"In the Old World are (1) the series in Kamschatka, the Kurile Islands; (2) the group of Japan; (3) the series south of Japan, including Formosa, the Phillipine and the Molucca Islands, and (4) the Australian series, including New Guinea, New Britain, New Hebrides and New Zealand. In this vast zone there are not less than four hundred volcanoes, one hundred and seventy of which are still active."

[The only difference in this description which we should propose to make, would be to call the American band one zone, and the Asiatic band another, whilst the Aleutian Islands, which in one sense connect the two, seem to be an independent range, forming an arc of a small circle in a plane parallel to the ecliptic,* and is therefore connected with, or rather parallel to the next zone.]

"*The second zone*, though less continuous, is hardly less remarkable. *It is the belt of broken lands and inland seas,*

* See Vestiges of the Molten Globe, Part I, page 45.

which extending round the globe, separates the northern from the southern continents, and intersects the first zone (two zones, W. L. G.) *in the equatorial regions nearly at right angles.* (The italics are ours).

"This zone includes (1) the volcanic regions of Central America and Mexico, and the series of the Lesser Antilles; (2) the groups of the Azores and the Canary Islands; (3) the Mediterranean Islands and Peninsulas, including all the active volcanoes of Europe; (4) Asia Minor with numerous extinct volcanoes; (5) the shores of the Red Sea and Persian Gulf, and the two Indias, rich in traces of volcanic action; (6) the East Indian Archipelago with hundreds of burning mountains, and (7) the Friendly Islands and other volcanic groups of the Central Pacific.

In this zone there are no less than one hundred and sixty volcanoes, so that the two volcanic zones together contain five hundred and sixty, or five-sixths of all known.

"The volcanic forces display the *greatest intensity* at the intersections of the two volcanic zones, in Central America and the East Indian Archipelago, nearly one-third of all known volcanoes occurring in these two regions. Central America, Mexico and the Antilles include eighty-five volcanoes, whilst the East Indian Archipelago possesses one hundred and seventeen."

But M. Guyot has said somewhat more respecting the distribution of volcanoes, although not directly under that head. It will be noticed that in the first paragraph quoted, he observes that nearly all the volcanoes on the earth's surface, are situated along the mountain ranges and belts of islands which skirt the shores of continents. Under the head of *

"III. DIRECTION OF ELEVATIONS.

He observes: "*All the great mountain systems of the globe extend in one of two general directions, approximately*

* Physical Geography, by Arnold Guyot, page 40.

at right angles to each other. The same is necessarily true of the general coast lines of the continents.

"They extend either east and west, with a slight deviation to the north or south, hence, in a direction nearly parallel to the ecliptic; or *north* and *south*, slightly deviating to the east or west, and therefore, on a line at right angles to the former. The Himalayas, the Alps, and the Atlas mountains are examples of the east and west directions; the Rocky mountains, the Andes, and the Blue mountains of Australia, have the north-south direction.

"Distinguished geographers in the last century had already noticed these two prevailing directions and designated them the meridian and parallel directions. A more correct designation, however, would be the *Ecliptic* and *Arctic Circle* directions. For the one makes an angle with the equator approximately equal to that of the ecliptic, while the other at right angles to the ecliptic, is indicated by great circles tangent to the Arctic Circle."

Taking all these paragraphs together, we find that the very important fact is recognized by Professor Guyot, *that all the grander accidents or lines on the earth's surface, namely, coast lines, mountain ranges, and bands of active volcanoes, occur in two main directions at right angles to each other, one system being on great circles tangent to the polar circles, and the other system on lines parallel to the plane of the ecliptic.*

Coast lines, mountain ranges, and bands of active volcanoes, are usually held to signify fractures in the earth's crust, and two systems of lines of fracture of the earth's crust, one of which is parallel to the plane of the ecliptic, or to the plane of the apparent annual course of the sun, and the other on great circles, exactly at right angles to that plane, indicate in the clearest manner one single cause for both systems of lines of fracture, and

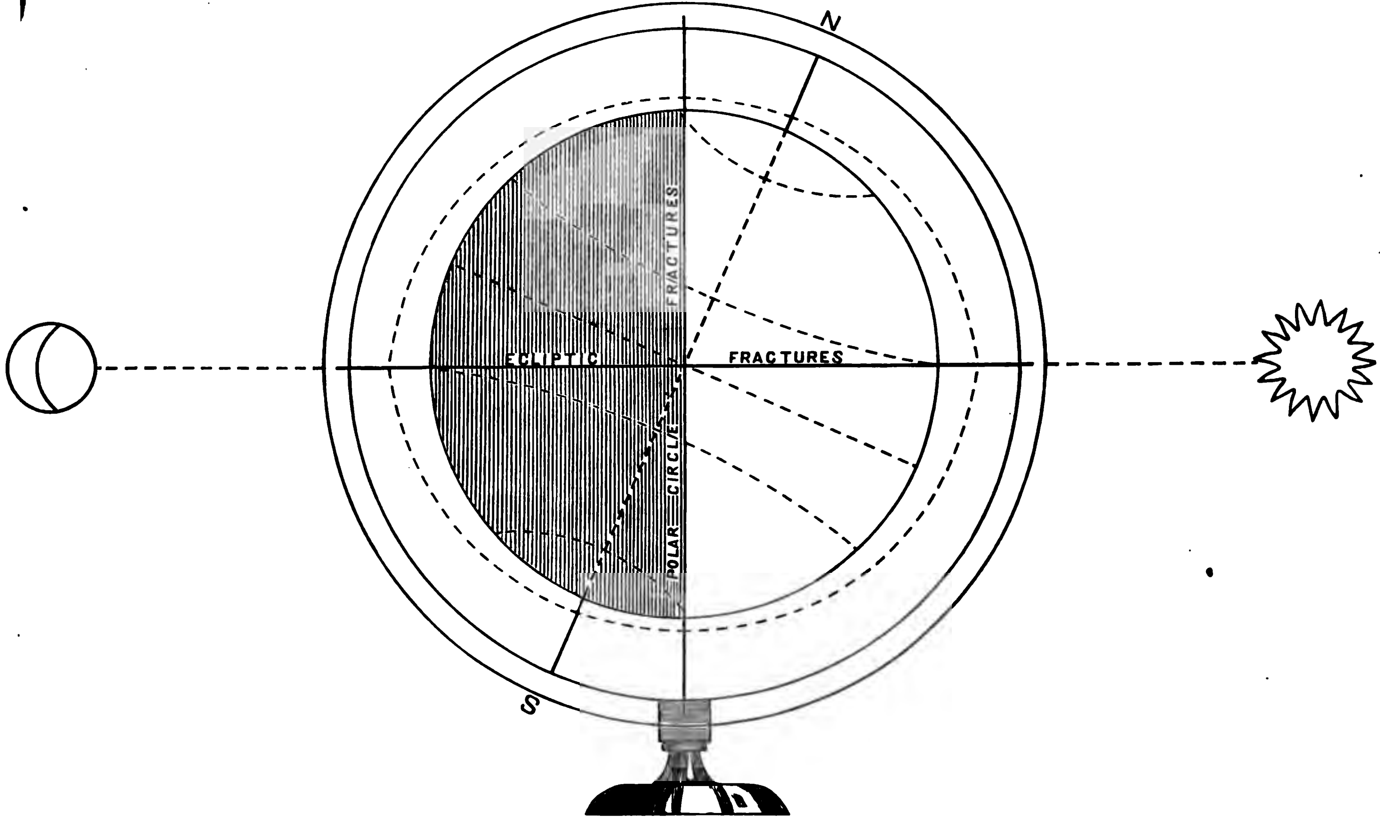

PLATE 1.

that cause to be connected with the attraction of the sun upon the earth.

These two systems of lines have been shown in Part I, on a map on Merçator's Projection, as well as by four copies of photographs of the globe,* but not so much in connection with the distribution of volcanoes, as with the direction of the continental coast lines and the division of the continents by the intercontinental seas.

That we should now have to refer to these maps to exhibit the distribution of volcanoes, corroborates the principles which Professor Guyot has laid down, of the connection of all these grand phenomena, and their appearance on the same two systems, of what we may well term, cosmical lines.

In order, however, to show more clearly the probable cause of these two systems of lines, a somewhat different form of representation will be found useful.

Let Plate I† represent the earth, sun and moon, as usually drawn, to illustrate the action of the tides, and the spring tides, but at the periods of the solstices. Instead of considering the superficial tide of the ocean, as represented by the dotted ellipsoidal line as generally drawn, let us imagine that dotted line to represent, (but in an exaggerated manner) the ellipsoidal elongation,

* One of these figures, showing the Asiatic coast line, was accidentally drawn with the polar circle wire, coinciding with the Corea, but not with the main coast line. The globe should have been turned 180 degrees. This, and other errors arose from the author not being able to superintend the publishing.

† The figure (Plate I) represents a globe mounted suitably to exhibit the lines on the earth's surface which coincide with the theoretical ecliptic and polar circle planes of fracture, by two fixed great circle wires; the ordinary thick wooden frame-work being supposed to be removed. It seems remarkable that the fact of the agreement of the main lines of accidents on the earth's surface, with the two planes of disruption, which would be due to the internal luni—solar tidal action at the periods of the solstices—as shown by this very elementary diagram, should not have been more generally taught. It is a fact independent of any theory; but the mere mention of the fact infers the theory.

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which the same attraction of the sun and moon would produce in the molten nucleus of the earth, assuming a thin crust.

It is evident from inspection of the figure, and it is an admittedly necessary mechanical effect, that such an ellipsoidal elongation of the earth's molten nucleus, as the rotating crust moved round the elongation, would tend to form two systems of fractures in the thin crust of the earth, one in the mean plane of the radius vector connecting earth, sun and moon, and of the movement of the crest of the elongation, (the ecliptic) and one exactly at right angles to both. The figure shows these two systems of lines, one in the plane of the ecliptic, and tangent therefore, to the two tropical lines, and the other system at right angles to these, and tangent therefore, to the two polar circles.

As the earth rotated (at the period of either solstice) different lines of fracture on great circles might be produced, in the direction of the polar circle fractures, on great circles all round the earth, and a number of ecliptic fractures, also on great circles all round the earth.

The first system, the polar circle fractures, when opposite, would cross each other in planes, at an angle of twice 23½ degrees, or 47 degrees, and at the equator the ruptures should exhibit this exact angle to each other.

The second system, the ecliptic fractures, when opposite would also cross each other on the equator, at an angle of twice 23½, or 47 degrees. Any combination of circumstances which would produce one of these ruptures in the earth's crust, would tend to produce at the same moment another rupture at right angles to it. Thus there are two sets of fractures crossing each other in planes at an angle of 47 degrees in each system, whilst the two systems are at right angles to each other—each set of one system to one set of the other system.

In order to be convinced that these two systems of frac-

tures or grand accidents on the earth's surface are real entities, and make with each other and with the earth's axis of rotation, the particular angles designated, it is only necessary to experiment with a common globe as pointed out by Dana,* following Owen. The very close, almost exact, coincidence of the coast lines to lines tangent to the two polar circles is quite remarkable.† Professor Dana concludes his remarks on these lines, as follows:

"But there are other equally important lines which accord with neither of these two systems, and a diversity of exceptions when we compare the lines over the surfaces of the continents and oceans.

"Still the coincidences as regards the continental outlines are so striking that they must be received as a fact whether we are able or not to find an explanation, or bring them into harmony with other great lines."‡

We shall see in the sequel that "other great lines are on the tetrahedral edges, or on lines coincident with, or parallel to the six great circles of the hexa-tetrahedral *reseau* produced on to a sphere. There appears to be a distinction in the systems of lines between the continental and the strictly oceanic areas. Both systems of lines, however, are often prevented from being traceable

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* Manual of Geology, third edition, New York, 1880; page 38.

† It is not to be expected that these great coast lines, which preserve one main direction, should keep a straight line in that direction. The different systems of fracture crossing each other not only tend to form peninsulas jutting out at an angle to the main coast line, but to produce a zigzag outline. If, for example, we cut two sets of lines transversely on a sheet of cardboard say one inch apart, and at an angle of perhaps 60° to each other, the cuts going only partly through the cardboard, and then bend the sheet more or less longitudinally—let us say 23½° from a perpendicular line—we should find that the bend partially follows the transverse cuts, producing a zigzag outline, although this would be in one average direction. The long cracks often observed in the plaster of a wall or ceiling, although they usually run in one main direction, present just this zigzag feature, and often simulate coast lines such as those on each side of the southern prolongation of Africa.

‡ *Ibid*, page 37.

all round the earth, by being covered with the waters of the ocean, and as already explained in (Part I.), their rectilinear direction has been shifted near the zone of fracture.

But to return to the probable cause of the two systems of astronomical accidents or fractures. It will be seen that both systems may well be the mechanical result of the daily rotation of the earth's crust around the comparatively fixed ellipsoidal tidal elongations of the earth's molten interior, which elongations remain theoretically in the mean plane and in the direction of the radius vector of the moon in her orbit, or in the plane and direction of the line joining the earth and sun, or in the plane and direction of the line joining the three, when sun and moon are in conjunction or in opposition. The plane of the ecliptic is the mean plane during each year, and at the periods when eclipses occur, this line and plane is practically in one direction. The periods of spring tides and of eclipses would probably be the periods at which the main ecliptic fractures, as well as those at right angles to the ecliptic—the polar circle fractures—have been first inaugurated, and afterwards accentuated.

To repeat, the mechanical effect would be to form at any moment two great circle fractures—one *in the plane* of the movement of the line connecting the earth and sun, or the earth, sun and moon (an ecliptic fracture), and another at right angles to that line and plane, and which might be anywhere between a meridian line and a line $23\frac{1}{2}^\circ$ from it, according to the time of year.

In other words, the relative movement of the elongated internal tidal ellipsoid tends to split the thin crust of the earth in halves in two directions at once at right angles to each other, one being in the mean plane of the movement of the crests of the two waves, and the other at right angles to the mean plane of that move-

ment, and at right angles to a line joining the earth and sun, the moon being assumed at that moment to be in conjunction or opposition.

But these conditions necessitate that the polar circle fractures—if to be attributed to this cause—must have been formed at or near the period of the solstices, and not at the equinoxes, or at intermediate periods of the year, because a fracture of the earth's crust at right angles to the plane of movement of the tidal elongation and to the radius vector at the equinoxes, would exactly coincide with meridian lines, and not with lines tangent to the two polar circles, whilst in intermediate relative positions of the earth and sun—that is between the period of the solstices and the equinoxes, the fractures at right angles to the tidal elongation would tend to occur in great circle directions, intermediate between a meridian line and $23\frac{1}{2}^{\circ}$ from it.

Is there, then, any mechanical reason why these polar circle fractures, if produced in the manner supposed, should occur at the period of the solstices rather than at the period of the equinoxes, or at intermediate periods?

It is evident that fractures caused in the earth's crust by the ellipsoidal tidal elongation of the nucleus would, as we have already said, tend to occur preferably when the sun and moon acted together, or at the time of the spring tides; in fine, at the time of the conjunction or opposition of the sun and moon. The solstices, let us remember, are the only periods in the annual revolution of the earth round the sun, which have any practical duration whatever, when, considering the question before us, that is the angle made with the earth's axis of rotation by a plane at right angles to the plane of the relative movement of the internal tidal elongation and the radius vector. They are the periods, twice a year, when the direction and tilt of the earth's axis,

compared with the plane of the ecliptic and the direction of the sun, practically stands still for several days together, that is, it is the time when the sun *stands* (as it is called) for several days together vertical over one tropical line or the other.*

Thus every day for many days at the solstices, the rupturing tendency of the internal tide-wave would be exerted in the same two planes at right angles to each other with reference to the direction of the earth's axis of rotation. One of these planes would be precisely tangent to the polar circles. More than this, for many weeks near the period of the solstices the sun stands *nearly* vertical over the tropical lines, and a line of fracture of the earth's crust at right angles to the plane of the movement of the crests of the internal tide-wave, and to the radius vector, would be closely coincident with a line of fracture at the solstices; and the latter once formed would tend to prevent a new fracture near them. At the equinoxes on the other hand, the sun rapidly alters its angle of inclination from day to day, and of course also it as rapidly alters the angle to the earth's axis, formed on the earth's surface by a plane at right angles to the plane of the sun's path and to the radius vector. Instead of pursuing a path tangent to, and therefore for many days practically coincident with the two tropical lines, as at the solstices, the sun is, at and near the equinoxes, rapidly crossing the equatorial regions. There is therefore less opportunity at or near the equinoxes for the sun and moon to combine so as to form fractures on the earth's surface at right angles to its path *in any one particular direction*, and therefore less opportunity for forming fractures at all, for in an action of this sort, time, or else a rapid repetition of the same rupturing force, in the same place,

* See Appendix. Reply to a notice and query by E. H. in the *Geological Magazine*, July, 1882.

must have been an important factor in producing the result.* The solstices and the periods near them are the only periods of the year when the rupturing effect remains practically for some time in one direction, when compared with the direction of the earth's axis. Thus there is a clear physical reason why luni-solar tidal fractures should occur at and near the solstices rather than at any other period of the year; and at that time one set of those fractures would be—as we find them—on great circles tangent to the polar circles, or at an angle of $23\frac{1}{2}°$ to the earth's axis of rotation.

As already observed, at the equinoxes, or at the time when the sun is vertical near the equator, the fractures due to the internal tide-wave should appear along a meridian line; but as fractures along meridian lines would be due also to the tetrahedral collapse, these north and south fractures may have relieved the disrupting strain of the luni-solar tide at these periods. The two systems of fracture, that is the north and south system (tetrahedral) and the polar circle system (N. $23\frac{1}{2}°$, east or west), would probably have given sufficient relief to the earth's crust without forming any fractures intermediate between a meridian fracture and a polar circle fracture, and which intermediate fractures do not seem to have occurred.

Other causes have sometimes been suggested for the existence of these two sets of polar circle coast lines,

* It is now well understood amongst mechanical engineers that a minute bending stress on an axle, shaft or girder, which would be a perfectly safe one, and far within the limit of elasticity of the material, becomes a breaking strain in the course of time when continually repeated; so that the safe limit of durability for these mechanical appliances subject to repeated minute strains is found to be a few years only—the time depending on the frequency of the repetition of the strains. The principle is familiarly illustrated when we try to break a piece of tough wire in our hands. We may bend it backwards and forwards at one point at a small angle many times without producing any apparent effect; but if we continue the bending backwards and forwards at the same point, and at the same small angle, the wire will ultimately break.

such as great cataclysmal floods rushing from the southern hemisphere towards the northern hemisphere; but there is this peculiarity about them, that the two sets of polar circle fractures crossing each other at an angle of twice 23½° or 47° result in peninsulas projecting from the main coast lines at exactly this angle. Thus the Corea and Cochin-China project at this angle from the great Asiatic coast line; and Florida projects at the same angle from the eastern North American coast line, whilst the peninsula of Yucatan projects at the same angle to the polar circle line of western North America, but in the opposite direction.

Floods, currents, or any similar class of causes which might produce accidents or lines on the earth's surface, in one particular direction, cannot very easily be conceived to have produced another set of accidents on that very line, so to speak, in the opposite direction. When, however, a mechanical cause is pointed out which would produce both sets of accidents in the precise direction in which they exist, it becomes strong evidence of that being the real cause. These peninsulas jutting out from and in opposition to the main trend of the coast lines and mountain ranges, and at a fixed angle to them, become test objects by which to estimate the value of the general theory. When, however, we find both sets of a system of accidents—the polar circle system—to be at right angles to still another system of accidents containing two analogous sets of lines—the ecliptic system—and all attributable to precisely the same mechanical cause, the evidence in favor of that cause being the real one seems complete.

Although the direction of the polar circle fractures and volcanic bands is attributed to the influence of an internal tide-wave acting at right angles to the direction of its movement, the particular portion of the tetrahedrally modified spheroid at which the polar circle

bands of *active* volcanoes mainly exhibit themselves, is on each side of the great Pacific depression.

The Thian Shan group of active volcanoes, generally considered anomalous, falls into place, however, by this manner of considering the facts, for they are on the border of a great depression and former ocean, although not on the borders of an ocean, at present, thus confirming what almost all geologists now admit, and what Humboldt long ago pointed out, that it is the grand depressions of the earth's crust—not the water of the ocean—which has the main influence in determining the position of active volcanoes. It may be that many more polar circle fractures have occurred upon the tetrahedroid than are now visible, but only those have been accentuated, or have become permanent fissures which have occurred at the great bends, or at the changes of curve between the oceanic depressions and continental protuberances. These polar circle fractures seem to have a special and definite relation to such portions of the continental areas.* Nor is it alone the great coast lines, and the mountain ranges and volcanic zones parallel to them, that conform to these two sets of polar circle lines ; we find that the courses of rivers and the shorter coast lines, not in equatorial or inter-continental regions, also conform to them. For instance, the two main trends of New Zealand are precisely on the two

*Mons. de Lapparent has explained in an article in the *Revue des Questions Scientifiques* of July, 1879, entitled "l'Origine des Inegalites de la Surface du Globe," how we may expect to find the eruption of igneous rocks—"dans le voisinage de la portion abrubte des plissiments" (p. 20), or on the borders of continents next the ocean depression, which has been most effectual in raising them. If these are the portions of the earth's crust where we may look for lines of fracture and igneous ejections from subsidence or collapse, they must also be the portions of the crust most easily ruptured by luni-solar internal tidal elongation. They are what have been called "lines of weakness," not, as we would suggest, because sediments have been deposited there, or for any other adventitious cause, but simply, as M. de Lapparent has pointed out, from their position on the borders of subsiding areas.

sets of polar circle lines. The Labrador coast and numerous channels near the arctic regions in North America run on great circles tangent to the Arctic circle, whilst at the extreme southern point of South America the two main trends of the Straits of Magellan coincide with two great circle lines tangent to the Antarctic circle—in fact, all are tangent to the two polar circles.

The polar circle fractures, although in some respects more pronounced than the ecliptic fractures, have had, perhaps, a less important influence than the ecliptic fractures, upon the earth's surface features. The particular direction of both has been a result of the tetrahedral collapse, or rather of the inclination of the earth's axis of rotation resulting from the change of figure. A fracture in the tetrahedroidal crust once made all round it, in or near equatorial regions, and parallel to the plane of the ecliptic, presents an opportunity, as above explained, for the action of the earth's rotation to effect the upheaving northern crust and the subsiding southern crust in middle latitudes, by sliding, the one to the westward and the other to the eastward, along one of such lines of fracture.

This gives a simple account of the reason why the great zone of fracture is not coincident with the equator, but is on a plane parallel to the ecliptic, and coincident with a fracture already made and constantly renovated by the movement of the crests of the internal tidal-wave.

The main line of ecliptic fracture is not within and tangent to the two tropical lines, as should theoretically be the case, on the hypothesis of its being the result of the movement of the internal tide-wave—if we were considering a true sphere; but we have to remember that the figure on which the whole hypothesis is based is that of a spheroid tetrahedrally modified, and of which

the tetrahedral *expansion* is in the northern hemisphere, carrying the crest of the internal luni-solar tide-wave to the northward of the equator, and therefore to the northward of the tropic of cancer, to which it should, in the case of a sphere, theoretically be exactly tangent.

Thus the zone of fracture between the two hemispheres, parallel to the plane of the ecliptic, as described by Professor Guyot, does not cut the equator at two equidistant points, but at two points which include a greater area between it and the equator in the northern hemisphere than in the southern hemisphere.

This northward position of the zone ot fractures is indeed the secondary origin of the great, massive and embryotic southern half-continent, Africa, whilst this very massiveness and northward position—and therefore affected by two forces in opposite directions—has caused it to be the fulcrum, or stationary mass, around which—and its northern half-continent, Europe, the rotation of the earth, acting differently on upheaved and subsided areas —has collected the half-continents, Asia and South America, thus forming the land and water hemispheres as explained in the last chapter.

All the irregularities in the great polar circle fractures, and in the volcanic bands which are on them, that is their appearing deflected eastward out of a straight line as we follow them to the southward and across the zone of fracture, are clearly traceable to the same relative shift between the crusts of the two hemispheres of the earth. Continents, mountain ranges, and volcanic lines, whether on polar circle fractures, or on tetrahedral fractures, have all been relatively displaced together along the line of this grand cosmical "zone of fracture."

Within ten degrees of either side of the central line of intercontinental fracture and shift, have occurred the larger portion of active volcanic phenomena which have

been recorded, that is, if we include, as we should, noted earthquakes and active volcanoes together. *

Starting from the neighborhood of the Straits of Gibraltar, the most northerly portion of the line, the great earthquake of Lisbon of 1766, is a notable instance of intense volcanic action in this region. † Travelling eastward, the Mediterranean volcanoes, the only active volcanoes of Europe, are too well known to need special mention. The deep shading along the coasts to be found in any map, showing the distribution of these phenomena, is sufficiently indicative of the intensity of volcanic action along this part of the line.

It is, however, perhaps, not so generally recognized to what an extent the northern coast of Africa has exhibited the prevalence of earthquake phenomena. Mallet however, refers to the frequency of earthquakes in Algeria and northern Africa, and to the "sites of prostrate edifices which mark the past magnificence of Carthaginian and Roman rule." ‡

As we proceed along the line eastward, Asia Minor and its ruined cities, justify the dark tint which the

* On page 41 of the first part of "Vestiges of the Molten Globe," it was inadvertently written that "Within ten degrees on either side of this line exist by far the larger number of the active volcanoes of the earth." This is not literally correct. It should have been expressed as in the text above, "the larger portion of active volcanic phenomena (including earthquakes) which have been recorded." By running over any of the numerous books which give accounts of notable earthquakes and volcanic eruptions over the earth, and putting down those which are recorded as having occurred within this zone, in one list, and those that are recorded as having occurred all over the earth outside of this zone in another list, the first will contain the greater number. Earthquakes, it should be remembered, are more indicative of the constant shearing strain, assumed to exist along this zone of fracture, than active volcanoes, but the distinction between strictly volcanic earthquakes and those connected with the grand movements of the earth's crust, has to be kept in mind, although the effects of both are exhibited in the same great zones, for they are each separate phases of one phenomenon—the earth's cooling contraction and collapse.

† Report on Earthquake Phenomena to British Association, page 18.

‡ Since the above was written the great Spanish-African earthquake of December, 1885, has occurred, which has been very generally recognized as one of those connected with mountain making.

earthquake maps assign to it, and which is continued along the zone down the Euphrates valley, along the coast of Persia and Beloochistan, and into Hindostan, where the line crosses the great flood of basaltic lavas of the central part of the Peninsula, and which has been sometimes referred to as an instance of great fissure eruptions, in contra-distinction to ordinary volcanic action.

The line then, after passing near the volcanic islands in the Bay of Bengal, strikes the Eastern Archipelago, perhaps the most marked instance of intense volcanic action in the world, especially about the regions where the polar circle volcanic band of Eastern Asia meets this zone at right angles, and is twisted out of its course by it.

It is interesting to note how the long line of active volcanoes in this Archipelago runs parallel to the central line of the zone of fracture; but the rectangular intersection of this zone by the eastern Asiatic volcanic band, on a polar circle fracture, and the crossing of the second set of ecliptic fractures with the first set, are almost equally remarkable. Here indeed—being completely in the equatorial regions, and therefore in the midst of the intersecting nodes of the two systems of fractures, at right angles—*each* system consisting of two sets of fractures at an angle of 47 degrees to each other—they have, so to speak, cut the Asiatic continent to pieces; and the relative shift between the northern and southern portions at this zone, thus cut up, has left a number of continental islands, of all shapes and sizes, many of them being apparently of the most fantastically designed and irregular contours: such as Borneo, Celebes, Gilolo and New Guinea. But in all this maze of apparently fanciful forms, we can clearly, and without any doubt observe the governing influence of the two systems of fracture of two sets each, by carefully rotating the globe,

whilst the two wires, as shown in Plate I, are over the Eastern Archipelago; then turning the whole globe round 180 degrees, we find the two great circle wires correspond with nearly all the coast lines which failed to agree with them when the Eastern Archipelago was under the opposite side of the wires. *

That the zone of fracture, after leaving the eastern Archipelago, should then encounter volcanic islands in its course across the Pacific Ocean, may perhaps be accidental, for all the islands in mid-Pacific are either volcanic islands, or coral islands which probably cover them.

But on arriving at the Central American coast, the line plunges through the midst of the dark shading of the earthquake maps, indicating intense volcanic action; a region again, where a polar circle volcanic band meets the ecliptic volcanic band, or the intercontinental zone of fracture, at right angles, and is turned from its direct course by it.

This part of the Central American coast has been said by Stephens to be "bristling with volcanic cones;" † and two hundred miles south of the central line of fracture and shift, is the capital city of San Salvador, which has been no less than eight times totally destroyed by earthquakes, since the settlement of the country by the Spaniards. About two hundred and fifty miles to the northward of the line, appears the great transverse fissure across Mexico, on which are situated six active volcanoes. The same thrust which appears to have pushed

* As a matter of convenience the globe might be fitted with two sets of great circle wires of two each, the polar and ecliptic, so as to obviate the necessity of turning it, and to be able to see at one view the coincidence at any spot of all the coast lines with one or other of the great circle fractures. It should be remembered, however, that the four wires represent *two* definite planes of action and no more, which coincide on continental, and on the half submerged intercontinental areas, with all the main coast lines, mountain ranges, and strings of islands and volcanoes.

† Central America, Chiapas and Yucatan, p. 339.

Central and South America out of line to the eastward, seems to have set up a shearing strain across Mexico, and on the resulting fracture appear the six active volcanoes referred to, namely: Colima, Jorullo, Toluca, Popocatepetl, Orizaba, and Taxtla, extending five hundred miles in an east and west direction, and across the general trend of coast line, the only instance of such a great transverse volcanic band on the American continent, from Behring Straits to Cape Horn. The ecliptic line then crosses the southern part of Cuba, on the trends of which island two intersecting ecliptic fractures are visible, whilst it passes close to a great crevice referred to by Humboldt as extending laterally, and which he says, "is believed to cross the neck of granitic land between Port au Prince and Cape Tiburon, and on which whole mountains were overthrown in 1770." *.

From hence the line crosses the deep ocean to the Strait of Gibraltar, where we commenced.

We have only to place the globe before us, arranged as explained above, and give it a small movement of rotation backwards and forwards, whilst the inter-continental region of the Carribean Sea, is under the wires, (as in the case of the eastern Archipelago,) to perceive —that all the coast lines in this region, whether long or short ones, and whether of continents or large islands, coincide with one or other of these great circles, as the globe is rotated and brings the coast lines under one or other of the wires. In the eastern Archipelago, the northern coasts of Borneo and Mandanao, two main branches of the Island of Celebes, and one of Gilolo, Timor, the southeast coast of New Guinea, New Britain, and the northern Australian coast, coincide with one set of ecliptic fractures, whilst New Guinea itself, the south coast of Borneo and the Archipelago of Lousiade,

* Humboldt's Travels, Vol. 3, Page 169.

coincide with the other set. The remaining coasts of Borneo and the other branches of Celebes and Gilolo, coinciding with one or other of the polar circle fractures, at right angles to the ecliptic systems.*

In the Carribean Sea we find that the long coast lines of Central America, and the north coast of South America, as well as the main parts of Cuba, Hayti, and Porto Rico, are on one set of ecliptic fractures, whilst the main courses of the Oronoco and Amazon rivers, one of the peninsulas and the south coast of Hayti, the north and the south peninsulas of Cuba, and the north coast of Yucatan, are on the other set.

The almost complete account which these two systems of fractures—the polar circle and the ecliptic—give of all the varied coast lines, mountain ranges and volcanic zones on the *continents and continental islands* of the earth, must be held to be a primary fact in the constitution of the crust of the globe, and one which has been recognized as such by the first physical geographers, quite independent of any attempt at explaining the causes of them.

The Mediterranean Sea and the northern coast of Africa, and the main range of the Atlas mountains, it has to be remembered, are also parallel to the ecliptic fractures, and to the assumed great line of shift along one of them, although they are not so readily compared

* Mr. A. R. Wallace, has not only remarked the likeness to each other of the "fantastic" shapes of the islands of Celebes and Gilolo, but he has observed (Island Life, page 350,) that a subsidence of Borneo of 500 feet would cause it "to resemble the form of the island of Celebes, to the east of it." These three islands, therefore, notwithstanding the remarkable singularity of their contours, or of the direction of their mountain chains, exhibiting four arms radiating in certain directions from a centre, are evidently constructed on one definite plan. The experiment with the globe and wires, as explained in the text, will show how well their configuration agrees with the hypothesis of islands situated at the intersection of the polar and ecliptic fissures, and that notwithstanding the amount of erosion and of marine denudation to which they have been subjected, their configuration still presents unmistakable evidence of the operation of special and definite telluric forces.

with the ecliptic wires attached to the globe, because they are outside the Tropics. The reason why this great continent has its northern coast and the Atlas range of mountains running nearly east and west instead of at an angle of 23½ degrees to a parallel of latitude, as the coasts of the Carribean Sea and of the eastern Archipelago do, is simply because their position on the ecliptic zone of fracture is due north of the point where the line is (theoretically) tangent to the Tropic of Cancer—that is, tangent to a parallel of latitude—instead of being more nearly in equatorial regions, as the coast lines of the other two inter-continental seas are, for on the equator, a coast line on an ecliptic fracture should trend exactly 23½ degrees north of east or west, but where the plane of the fracture is tangent to either tropic, or to a parallel of latitude, it should trend exactly east and west.

The coast lines, mountain ranges and volcanic bands coinciding with the plane of the ecliptic, or parallel to it, are found mainly between the Tropic of Capricorn and 13 degrees north of the Tropic of Cancer. The main line of shift along one of these—Guyot's zone of fracture—is on one of the most northward of them. One of the most remarkable however, of the volcanic fractures parallel to the plane of the ecliptic, is that of the Aleutian Isles, which appears on an arc of a small circle, which meets two polar circle fractures at right angles. This volcanic line may be used as another test object by which to guage the consistency of the general theory, for instead of being on the great circles of the eastern Asiatic, or of the western American volcanic bands, and where even good physical geographers have endeavored to place them, the Aleutian line of volcanoes, with the peninsulas connecting them with the main land, meet the Asiatic and American bands exactly at right angles, and the arc of a small circle formed by them, has the

same centre as the great zone of fracture parallel to the plane of the ecliptic, so that this volcanic arc is also parallel to that plane.

It may fairly be said, that the cut up and half-submerged continental regions of the three inter-continental seas, as well as the portions of the continents immediately north or south of them, have been, as far back as history records, and are, up to this hour, in a more or less constant tremor. The chances are, that whenever the reader may peruse this, he will remember some comparatively recent account of a violent earthquake or great volcanic eruption, in one or more of these three inter-continental regions—that is on Guyot's great zone of fracture. There have been several notoriously severe earthquakes and volcanic eruptions, quite lately in Panama, Central America and Mexico, the Mediterranean and the eastern Archipelago. * It should be borne in mind, as we have before remarked, that earthquakes are even more significant than active volcanoes, of the action assumed to be continually going on, along this great volcanic fissure or zone of relative movement in opposite directions, between the northern and southern hemispheres of the earth's thin floating crust.

The strictly oceanic volcanic islands do not appear prominently along the ecliptic zone of fracture, whilst the polar circle volcanic fissures seem to show themselves exclusively on continents or on continental islands. Professor Guyot observes:

"The *volcanoes not included* in these two great zones *are isolated in the midst of the oceans*, or in the broken polar lands. The most noted are the Sandwich Island Group, in the Pacific; Bourbon and the Mauritius in the

* The earthquakes and volcanic eruptions which we read of, are usually those extensive and violent ones that destroy cities, often over large areas of territory. Remembering the frequency of the less noted earthquakes in highly volcanic countries, these inter-continental regions may be said to be continually quivering.

Indian ocean; Cape Verd Islands, Ascension, St. Helena, Tristan da Cunha, in the Atlantic; Iceland and Jan Mayen, in the Arctic Ocean; and Erebus and Terror, in the Antarctic."

It may be observed here, that of the above, Jan Mayen, Iceland, Cape de Verd Islands, Ascension, St. Helena and Tristan da Cunha, have been, and may be grouped together as forming one band of oceanic volcanic islands, down the central portion of the Atlantic ocean, and maintaining the same double curve that the Atlantic itself does, thus conforming indeed to the pattern, if we may so call it, of the map of the world. This volcanic band seems as if it may be on a north and south tetrahedral fracture, in a central line of oceanic depression and through which the molten matter has issued, but twisted out of a straight meridian line by the relative shift of the two hemispherical crusts, as we find all the other great north and south accidents of the earth's surface, and the continents themselves have been. * They are corroborative of the grand relative shift shown by the continents.

The Rev. O. Fisher has also inferred that the two classes of volcanoes, continental and oceanic, not only differ from each other in mineralogic composition, but are to a certain extent disconnected in their mode of origin. He observes:

"We recognize two principal types of volcanic regions, coast line and oceanic. We believe the former to be connected with the agencies which have raised the continents which they skirt. Trains of vents are attached laterally to the great compressed and elevated ranges, and usually stand near the edge of a steep shore. The oceanic volcanoes, on the other hand, appear unconnected with true elevatory action, for the oceanic

* See Appendix. On Mr. G. H. Darwin's hypothesis of the distortion of the earth's surface features, etc.

islands consist, almost all of them, of volcanic rocks, whereas if they were connected with areas of elevation, the peaks of schistose, or other hard inclined strata could not well be absent." *

We shall find, indeed, that the true oceanic volcanic islands appear on an entirely different set of fractures to those on which are situated the great continental and inter-continental bands of volcanoes. They occupy the grand central depressions, or areas of general subsidence, instead of the borders of the great continental flexures, and have their own direction of allignment. They may well therefore, be classed and considered by themselves. Although the distribution of the continental and inter-continental volcanoes—by far the larger portion of all the volcanoes on the earth's surface—is thus referred mainly to an astronomical cause, it is by no means an isolated phenomenon, but is, as we have seen, one intimately connected with all the other grand physiographic features of the globe, which have been evolved as a correlated series of events. The first result of the loss of heat by the molten spheroid, has been the formation of a thin spheroidal crust, as the earth then rotated with its axis of rotation at right angles to the plane of its orbit. As the molten interior lost volume from the excess of loss of heat, it and the non-contracting hardened crust, mutually accommodated their relatively altering dimensions, by approaching the regular figure which most easily produced that result.

This tetrahedral modification of the spheroid, resulted in tipping the earth's axis of rotation by the attraction of the sun and moon on the salient angles of the new figure in the northern hemisphere, until that figure assumed a position of comparative repose, disturbed only by the same attractions, on the now altered relative po-

* Physics of the Earth's Crust, by the Rev. Osmond Fisher, M.A., F.G.S., London, 1881, page 289.

sition of the equatorial bulge—precession and nutation —and which bulge still necessarily existed, as the result of the earth's rotation. The tide-generating influences of the same attractions on the molten nucleus then produced two systems of fissures in the now deformed and inclined spheroidal figure, one system parallel to the plane of the movement of the tidal elongation, and the other system at right angles to that movement, but appearing deflected in the southern hemisphere to the eastward, by the mechanical action of the earth's rotation on the grand collapsed and upheaved areas. Thus the particular *direction* and *position* of the great "polar" and "ecliptic" or astronomical volcanic fissures present themselves as the definite result of the original tetrahedral collapse, a process exclusively terrestrial.

It may be a matter of some geological interest to note, that according to this view, these grand astronomical accidents of the earth's crust, the volcanic bands which are on them, and the earth's great features and continental sub-divisions—and which have governed the distribution of animal and vegetable life—were necessarily by the hypothesis, formed, or at least inaugurated —vast geological ages ago truly—but when the angle of inclination of the earth's axis of rotation to the plane of its orbit, was substantially the same as it is to-day, and not when it was perpendicular to that plane, or more inclined to it, or in fact at any other angle of inclination to it whatever. *

It seems unnecessary to add that this view of the facts of the distribution of volcanoes, appears to be irreconcilable with the hypothesis of a solid earth. As has been remarked by Darwin, Humboldt, Jukes and others, the simple existence of great linear cracks in the earth's crust, coincident with lines of active volcanoes, suggests

* See Appendix, page 378. On the change of inclination and of the position of the earth's axis, due to a change of figure.

that a general molten substratum lies below it, and thus escapes to the surface. But when the cause of these vast fissures, on lines which are often for long distances, on great circles of the sphere, is shown to be, in all probability, extra-terrestrial, or definitely—may we not say mechanically—related to the mean plane of attraction of the sun and moon; the molten matter everywhere proceeding from them, becomes almost conclusive evidence of the existence of a thin crust of the earth and of a molten substratum beneath it.

CHAPTER IV.

VOLCANIC MATTER. WHAT IS IT?

"La composition des masses meteoritiques nous apprend enfin, comme on l'a vu que les corps celeste passent, ou on passe, par des evolutions chimiques, analogues a celles dont les regions profondes de notre planiete presentent des indices et dont il parait possible d'entrevoir la nature. Elle nous ramene donc, par des nouveax arguments, a la grande hypothese, par lequel Laplace (en 1794) a si heureusement cherche a explique tous les movements de notre systeme planetaire, ou faisant deriver la Terre, comme tontes les autres planetes, d'une masse unique

"En constatant entre les meteorites et les massess profondes de notre globe, des liens d'une intimite surprenante, nous arrivons ainsi, non seulement a d'evoiler les phases les plus reculies de l'histoire de notre propre globe, mais encore a faire ressorter la parente mutuelle des differentes parties de l'Univers.—DAUBREE." *

It has been well said, that when we know the cause of the difference between trachyte and basalt, we shall understand the theory of volcanic action. We shall certainly know a great deal about what goes on in the depths below, when we obtain a clear knowledge of the cause of the difference between the two main classes of lava ejected by volcanoes.

It may seem a simple matter to turn to our text-books, and ascertain what volcanic matter is. It is true we shall there find a list of the names of the rocks which are usually admitted to proceed from volcanoes, with the names also of the minerals and of the elements com-

* Etudes Synthetiques de Geologie Experimentale, par A. Daubree, Membre de L'Institut. Inspecteur General des Mines, etc., etc., Paris, 1879.

posing them, but our knowledge of volcanic rocks is really small, for the moment we begin to enquire into the meaning of some of the simplest and most marked features concerning them, we have nothing but crude guesses to fall back upon.

For example, if we enquire the reason why there is an acid (or silicated) and a basic series* of lavas, we have nothing more satisfactory in reply than Durocher's hypothesis of the two magmas; a forced explanation, and hardly more than another method of stating the fact, that two such series of rocks are ejected to the surface, and imagining that the same two series may exist universally down below in a liquid state, but separated from each other, the less dense layer being uppermost.†

Again if we endeavor to ascertain the cause of the difference which exists between ancient and modern lavas and igneous rocks, we find ourselves involved in discussions, but with no definite reply; some contending that the differences are original and essential, others that the ancient lavas were formerly identical with such as are ejected to-day, but now appear altered by atmospheric and other agencies, during long periods of time. One school insists that certain igneous rocks with distinct and characteristic minerals, should be considered as separate species and have distinct names. Another school

* It was Elie de Beaumont, who first divided the rocks into these two great classes; who, in fine, pointed out the first grand scientific classification of rocks.

† It is a question whether a comparatively thin stratum of a molten acid magma with free quartz in it, could exist for any length of time floating on a basic stratum, and one of presumably higher temperature on account of its greater depth. The silica of the upper stratum would go on combining with the bases of the lower one, so that the basic substratum would gradually eat into and destroy the acid one, so far at least, as it might contain free silica. This effect need not, however, be rapidly produced in narrow fissures, where the area of the surface in contact is small compared with the volume of each, and where the overlying acid layer may be more viscous from cooling, and lighter by the mixture with steam and water which is in the sequel assumed to be the cause of its separation from the general basic substratum in such fissures.

shows that the distinct minerals are often the old ones changed by decomposition and recomposition, that the rocks were originally identical, and therefore should not, in such cases, have new names ; to which it has been retorted, that on this principle there would be very few species of rocks, and that in truth, this decomposition and recomposition is the main difference which exists between all rocks whatever.

Whilst some mineralogists of the highest standing, tell us that minerals can be no test of the geological age of a rock, others of equal repute assure us that many minerals are like fossils, and will constantly indicate the position of a rock in the geological series.

Geological literature is full of discussions as to whether large classes of rock are igneous, or sedimentary and metamorphic, or igneous and metamorphic ; whilst some writers go so far as to contend, that all lavas whatever, are metamorphosed sediments, poured out in a state of aqueo-igneous fusion. *

Thus when we attempt thoroughly to follow up the enquiry, as to what volcanic matter is, we find that a satisfactory answer involves the whole subject of the nature of volcanic action.

If we go more into detail a similar difficulty arises. In traveling over the Hawaiian group, and particularly amongst the recently erupted lava streams, we are struck with the universal prominence of one mineral, olivine ; it seems to compose about half of many of the lava flows. It glitters on the roads, and grinds down the hoofs of our unshod animals. It is found in small specks in the volcanic glass called Pele's hair, it is in large crystals, in the *aa* streams, in more rounded grains in the *pahoehoe* streams, and in agglutinated lumps in the tufa craters.

* Dr. T. Sterry Hunt, Chemical and Geological Essays. Boston, 1875, p. 8.

It forms with coral, the sands of the sea shore, and is constantly mixed with the coral reefs and coral sand rocks all round the islands. It seems indeed, to occupy the position in the Hawaiian Islands—being the hardest mineral of our rocks—that the quartz in sand occupies in continental countries. *

Now if we turn to our books to find something about this mineral, some of them refer to it as an accessory mineral, lining cavities in vesicular dolerite. † If we look for its place in some of the mineral classifications, we find a no less authority than Weiss, placing it under the family of Gems along with the Emerald and Topaz; many geologists have not included it in their lists of the main rock-forming minerals at all. But the stone which the builders rejected seems likely to become the head stone of the corner, and recent research brings to light the fact, that this heretofore neglected mineral is one of primary importance in the study of rocks. M. Daubree calls it the universal scoria. ‡

Is there no indication of some guiding principle, or method of considering the subject, which may unite these incongruous views, into an harmonious system? Although we are approaching the subject of mineralogy from the igneous side, we may obtain some valuable hints from that philosophical mineralogist Gustav Bischof, who, as J. D. Dana observes, "arrives at a Neptunian theory, making nearly all rocks by the wet way;" and

* It is perhaps, unnecessary to remark that this position of olivine sand, compared with quartz sand can only be temporary, as, although olivine is one of the hardest, it is at the same time one of the most easily decomposed minerals, by chemical or atmospheric action.

† Olivine is not an accessory mineral, it does not line cavities, and cannot be said to be peculiar to *vesicular* dolerite.

‡ With reference to the observation which M. Daubree has made regarding the scarcity of olivine now visible in the earth's crust, we would suggest that if we may take the rocks of the strictly oceanic volcanic islands, as an indication of those which exist generally over the deep ocean beds—underneath the superficial deposits—and this seems probable—olivine would be one of the most widely dispersed minerals.

notwithstanding that Dana adds to this, the remark, "in which few will follow him." *

But under the control of recent discoveries and synthetical experiments, his principles seem to lie at the foundation of the cause of the main differences of minerals and rocks.

Bischof's leading principle was, that a very large proportion of all minerals are formed from other minerals, principally through the agency of water and the carbonic acid, alkalies, and other re-agents which it may contain. His views have been corroborated by many subsequent writers. M. Daubree has illustrated Bischof's principles by many interesting synthetic experiments, and by referring to what has actually taken place in the way of the formation of minerals, through the agency of moderately warm water, in the bricks and mortar of old Roman baths at Plombieres and elsewhere.

Having shown the great significance of the principle, Bischof looked round to find what were probably the original minerals, from which all others were derived; to inaugurate in fine, a natural system of mineralogy. He appears, however, to have abandoned this attempt, and says:

"It is in vain therefore, that we seek to ascertain which are original minerals and rocks; in vain that we seek to ascertain the beginning and end of the series of alterations in rocks; and the distinction between primary and secondary minerals to which I still adhered but recently, disappears more and more as investigation progresses."†

Since Bischof wrote the above sentence, however, many mineralogists and geologists have suggested, that certain minerals and rocks, may in all probability be looked upon, as the original minerals and rocks from

* Manual of Mineralogy, by J. D. Dana, page 36.

† Elements of Chemical and Physical Geology, by Gustav Bischof, P.H.D. London, 1854. Printed for the Cavendish Society. Vol. III, page 364.

which the others have been derived. The late J. B. Jukes remarked, in his excellent Manual of Geology:

"Although many of the rarer silicates occurring as endomorphs, perimorphs, or pseudomorphs, throw great light on the genesis and metamorphosis of rock masses, the number, a knowledge of which is absolutely indispensable to the student in order to study lithology is small. These belong chiefly to the augite, olivine and felsdpar groups—which may be considered the primitive mineral constituents of crystalline rocks; the garnet, or epidote, mica, leucite, nepheline, hauyne, talc, serpentine, chlorite, pectolite, and zeolite groups, as their intermediate and secondary constituents." *

A rock consisting of augite, olivine, and basic feldspar, would be a dolerite or basalt; and J. D. Dana has, from other considerations inferred that: "the nature of the first formed crust, or of the liquid material of which it was made by cooling," † was dolerytic, or basic. Dr. T. Sterry Hunt writes on this subject as follows, so far confirming Dana:

"In this way we obtain a notion of the processes by which, from a primitive fused mass, may be generated the siliceous, calcareous and argillaceous rocks, which make up the greater part of the earth's crust, and we also understand the source of the salts of the ocean. But the question here arises whether the primitive crystalline rock, which probably approaches to dolerite in its composition, is now anywhere visible on the earth's surface." ‡

But perhaps, the most valuable suggestion which has been made in this regard, and which leads to the same con-

* The Student's Manual of Geology, by J. Beete Jukes, M.A., F.R. S. Edinbnrg, 1872, page 71.

† Manual of Geology, by J. D. Dana, 2d Edition, New York, pages 736, 737.

‡ Chemical and Geological Essays, by Thomas Sterry Hunt, LL.D, Boston, 1875, page

clusion, has proceeded from M. Daubree, who, in a paper in the Annales des Mines, in 1868, under the head of "Synthetic Experiments relative to Meteorites—Approximations to which these Experiments lead," called attention to the importance of considering the nature of the minerals in meteorites, or those samples of cosmical matter which visit us from the depths of space, and showing that they also consist of the augite, olivine and basic feldspar groups, with more or less native iron, nickel, etc., the same minerals and metals in fact, which come up from the lowest depths of volcanic or igneous regions. *

When we find that this dolerite or basalt seems to exist everywhere all over the earth, below the more silicated rocks, and in a fluid state; and whilst at the same time our general enquiries lead to the inference of a universal molten basic substratum, it becomes a circumstance of the highest moment to find, that this fluid internal substratum, is nearly identical with the substance of almost all the planetary bodies which have happened to reach our earth. M. Daubree, also reminds us that the spectroscope indicates the same basic elements in the sun and stars. He not only brings forward the facts relating to meteorites as another confirmation of Laplace's grand nebular hypothesis, and the derivation of

* Professor J. W. Judd, announced at the meeting of the Geological Society of December the 1st, last, (1886) "that he had received from Professor Ulrich, of Dunedin, New Zealand, the announcement of a very interesting discovery which he had recently made. In the interior of the South Island of New Zealand, there exists a range of mountains composed of olivine-enstatite rocks, in places converted into serpentine. The sand of the rivers flowing from these rocks contains metallic particles, which, on analysis, prove to be an alloy of nickel and iron, in the proportion of two atoms of the former metal to one of the latter. Similar particles have also been detected in the serpentines. This alloy, though new as a native terrestrial product, is identical with the substance of the octibeha meteorite, which has been called octibehite.". *Nature*, December 23d, 1886, page 190. The importance of this discovery on the questions raised in this chapter can hardly be overestimated. Its different bearings will readily occur to the mineralogist or to the student of vulcanology.

the earth and all the other planets from a uniform mass, but at the same time presents us with a basis for the study of mineralogy, and a rational, though broad answer to the question, what is volcanic matter.

It becomes therefore, of no less primary importance to find, as M. Daubree has pointed out, that the whole series of the silicated rocks and minerals are *not* found amongst these extra-terrestrial bodies. We cannot do better than quote from the above named paper the entire paragraph headed:

"ABSENCE IN THE METEORITES OF STRATIFIED ROCKS OR OF GRANITE.

"Meteorites, so analagous to certain of our rocks, differ considerably from most of those which form the terrestrial crust.

"The most important difference consists in the fact that, in the meteorites nothing has been found which resembles the materials that constitute the stratified formations—nether arenaceous rocks, nor fossiliferous rocks, that is to say, nothing which testifies to the action of an ocean on these bodies any more than to the presence of life,

"A great difference is manifested, even when we compare the meteorites with the terrestrial rocks not stratified. Never has there been met with, in the meteorites either granite or gneiss, or any rocks of the same family which form, with these, the general layer on which rest the stratified formations.

"We do not even observe there any of the constituent minerals of granitic rocks—neither orthose, nor mica, nor quartz—any more than tourmaline and other silicates which are associates of those rocks.

"Thus the silicated rocks which form the envelope of our globe, are wholly wanting among the meteorites. It is, as has been seen above, in the deeper regions only,

that we must seek the analogues of these latter; in those basic silicated rocks which only reach us in consequence of the eruptions by which they have been expelled from their primitive repository. In every point of view, the absence in meteorites, of the whole series of rocks which constitute, to so great a depth, the crust of the earth is a circumstance well calculated to arrest attention, whatever may be the cause.

"This absence may be explained in different ways; whether it be that the meteoric fragments which reach us do but proceed from the internal parts of planetary bodies constituted like our globe; or whether these planetary bodies themselves are deficient in silicated quartziferous, or acid rocks as well as in stratified formations. In this latter case, which is the most probable, they must have passed through evolutions less complete than the planet we inhabit, and it is to the co-operation of the ocean that the earth has owed, in its origin, its granitic rocks, as it has owed to the same agency, at a later period, its stratified deposits." *

It is an hypothesis favorably regarded to-day by a large number of geologists, that not only the gneisses and schists, were originally stratified rocks, but that granite itself may be a quasi re-fused condition of the same rocks, (aqueo-igneous fusion, so-called) so that all such acid, or granite rocks, may be derived from the basic, through the agency of the ocean, or the water derived from it; not necessarily at an earlier or rather at a distinct epoch; but they become, on this view, the earliest stratified deposits which have undergone a partial re-fusion, or re-crystalization, sometimes to appear as molten acid lavas, and sometimes as cooled masses of granite.

It may be further worth considering whether the ac-

* Synthetic Experiments relative to Meteorites, etc. (Translated for the Smithsonian Institution.) Annual report, Washington, 1869.

cess of water to molten dolerites, may not have the effect of depriving them of their bases and making them more acid. It seems of some importance to note, that not only are the characteristic minerals of granite absent from meteorites, but the characteristic minerals of the acid volcanic rocks—these forming rhyolites and sanadin-trachytes—are also absent from them. It is certainly noteworthy, that whilst olivine, augite and basic feldspar, should be both volcanic and cosmical minerals; sanadin, black mica, and quartz, should be volcanic but not cosmical minerals; whilst they seem to represent, amongst volcanic products, the minerals of non-volcanic granite. May we not then, reasonably suspect, that the same order of causes which developed the granites from more basic rocks, may have developed the acid lavas from the basic?

Although the minerals of the acid lavas are largely distinct from those in granite, it is well known that the chemical composition of both is almost identical, but it seems to require something more than a simple re-fusion, or more than a difference in the circumstances of cooling to convert granite to trachyte or rhyolite, or *vice-versa.*

If further examination should warrant us in supposing it probable that the rhyolites and sanadin-trachytes may be the universal basic magma, accidentally (so to speak) metamorphosed and deprived of their bases by the action of water and steam, and what the water carries with it, and whilst still in a state of what has been called aqueo-igneous fusion, one great difficulty which has occurred to some geologists in admitting a liquid nucleus of the earth, as a means of explaining volcanic action, would be removed. For they ask, how can lava so distinct as basalt and rhyolite, proceed from the same or neighboring openings, if we are to imagine that they proceed also from a universal liquid substratum. The

percolation and access of the requisite quantity of water to a pipe or fissure containing the basic magma, in one place and not in another, might then be a sufficient answer; whilst the partial access of water to the basic molten lavas might help to account for the trachy-dolerites and other recent lavas of a composition intermediate between acid and basic. We leave out of consideration, for the moment, the effect which must be produced on basic lavas by their rising in fissures through the acid, or old rocks, whether these be the results of metamorphism, promorphism, or primitive cooling.

Have we then, any indications that the acid lavas have been subjected to the action of water or steam, to a materially greater extent than the basic lavas have? This is a question which mineralogists and geologists can best answer, but there are some points in connection with it which seem to be worthy of special notice.

It will be unnecessary to urge upon geologists the important role which water plays in those volcanoes which furnish them with most of their data. Indeed the difficulty will be to satisfy them, that in some of the greatest volcanoes of the earth, where the lavas are purely basic or ultra-basic, water seems to play an entirely subsidiary part, or is absent. The most recent text books on volcanic subjects are full of paragraphs, showing the effects of water; for example:

"We may very likely, for shortness sake, talk of 'fused' or 'molten' lava, but the reader must not for a moment suppose, if we use such phrases, that we are speaking of matter liquified in the dry way, by heat alone; he must carefully bear in mind, that lava, however high its temperature may be, always contains water, and that the crystalline texture which it assumes when it cools, is very largely due to the influence of this water." *

* Geology, by A. H. Green, M.A., F.G.S. London, 1882, p. 341.

Again: "While speaking of Mr. Scrope's speculations we must not forget to mention that he did inestimable service by showing that whatever be the origin of lava, the force that raises it to the surface is undoubtedly the expansive power of steam. There is no difficulty in obtaining water; very nearly every one of the known active volcanoes is situated near the sea, and percolation would furnish a plentiful supply." *

Professor John W. Judd, in a quite recent work on volcanoes, says:

"And that the varied appearances, presented alike in the grandest and feeblest outbursts, can all be referred to one simple cause—namely, the escape from the midst of masses of molten materials, of imprisoned steam or water-gas." †

Professor Judd has many paragraphs to the same effect, and after suggesting (page 354) that the principle of the occlusion of gases, by molten substances especially, may be a possible cause of the gases found confined in molten lavas, refers (page 359) to M. Daubree's valuable experiments, showing how "the percolation of water through rocks, takes place in opposition to the powerful pressure of steam in the contrary direction." "Hence," (he continues,) "we may assume that certain quantities of water, containing various gases and solids in solution, are continually finding their way by capillary infiltration from the surface to the deeply seated portions of the earth's crust, there to undergo absorbtion by the incandescent rock-masses and to produce oxidation of some of their materials."

May we not well add to the above—and to produce various chemical changes—not the least important of which would be, in a basic magma, the formation of

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* *Ibid* p. 677

† Volcanoes, what they are and what they teach, by John W. Judd, F.R.S., Professor of Geology in the Royal School of Mines, London, 1881, page 38.

quartz, and the separation of the acid and basic elements?

We seem now to be in the position of having proved too much, for if this access of water to the molten matter below is universal, and if it is unquestionably, as so many geologists contend it is, the main cause of the extrusion of all lavas, we cannot so well appeal to it as the cause of the difference between trachyte and basalt.

It must be a fundamental fact to settle, in limine, in studying the nature of volcanic matter and volcanic action, whether or not, immense eruptions of lava have occurred in past time, and do occur to-day, without the intervention of water and steam, except as an entirely subsidiary effect, and not in any respect necessary for the interpretation of the facts of the composition of the typical basic lavas, of their liquidity, or of the dynamics of the volcanoes which emit them.

As far as we are able to judge, from what we have observed in the molten dolerites or basalts of the Hawaiian Islands—and they are typical of the basic and ultrabasic lavas of the globe—the fusion is a pure igneous fusion, and that it is molten in precisely the same sense as iron or slag is when it flows out of the furnace. There is very constantly air, and possibly sometimes steam and occluded gases mixed with it, but these latter are, we are inclined to think, not more mixed with our lavas than they are with molten iron. The fluidity appears to be substantially the fluidity of fusion. *

J. D. Dana, in the late edition of his Manual of Geology writes as follows:

"*Temperature of Fusion* :—The temperature of the lavas of large free-flowing craters in full action, is often not less than 2.200 degrees F., within two or three feet of

* The olivine being the least fusible mineral, very soon solidifies, and is often found in solid grains in the molten lava, but this is the effect of partial cooling.

the surface; and the feldspathic and augitic (or hornblendic) portions are in complete fusion.

"The crysolite and magnetite, present in much of the rock, are infusible minerals, and hence may be solid grains floating in the lava. The Eifelbombs are evidence that this was the condition in the vent whence they were ejected. But their condition below was uncertain.

"(*a*.) The above statement as to the degree of heat is proved by facts at Kilauea, over the great lake of lavas in the pit, in 1840, the play of jets brought into view the hotter lavas beneath them, and produced a brilliant spangling of white light. The jets were but sixty to three hundred feet in height, and hence the white-hot lavas beneath, brought into view by the movements, were quite near the surface. This indicates a temperature of at least 2.200 degrees F. The heat is sufficient, not only to retain the lavas in a melted state, but should they become thickly crusted over, to re-melt the hard crust (after first breaking and submerging it,) and make it join in the boiling.

"(*b*.) The fusion of the labradorite and augite, the chief constituents of the lava was complete. The volcanic glass of Kilauea has the composition of ordinary dolerite. * * * This glass, hence contains the feldspathic and augitic ingredients in complete fusion, and at a low temperature compared with that of the mass of lava; for the glass is from the superficial scum of the lava pool, the fibres being made by the transporting winds carrying off points from the lava jets." *

Again: "The view that the fusion of lavas is due to the combined action of moisture and heat, or is *aqueo-igneous*, was early presented by Scrope, and has been held by later writers. But while the steam present in them increases their mobilily it does not appear in view

* Manual of Geology, by James D. Dana. third edition, New York, 1880, page 743.

of the above mentioned facts, to be essential to their fusion and flow." †

It is true we have sometimes spoken with intelligent but casual observers of Hawaiian molten lavas, who have received the impression that they are not very hot, or at a red heat merely; but we must confirm Dana's observation that whenever an opportunity offers for a moment, of getting a sight beneath the surface of recently erupted molten lava, or even of the surface itself, if seen through a small opening in a duct or tunnel, or through a blow-hole in the crust over a lake, it is constantly seen at a *dazzling white heat.* It is well known that such a shade of color in any substance whatever, means without doubt, a very high temperature—anywhere from about 2.200 degree to 3.000 degreess F., at any rate—and we should be inclined to place the temperature of Kilauea and Mauna Loa lavas at nearer the latter than the former figure, wherever it is in large mass connected with the source, and protected from radiation either by a cover of rock or by its own cooled scum. The eyesight is often a better guide to the temperature of lavas for those who have been accustomed to observe molten iron and other metals, than the experiments, generally futile, which have been attempted at melting the different metals in them, for these either remain unmelted in a cooling surface layer, or if they melt, it only shows that the lava was probably much hotter than the melting temperature of the metal. A dazzling white heat, however, which is nearly always to be seen when the surface layer has not been chilled, means a close approximation to 2.900 degrees F. We admit that an observer might, by chance, look at a lava lake in Kilauea, or indeed, any flowing lava stream, for some hours, without getting an opportunity of seeing the white-hot lava beneath the surface.

† *Ibid*, page 744.

Indeed the rapidity with which a surface layer of this white-hot doleritic lava will flash into a black glass, when suddenly exposed to radiation, is marvellous. It has been constantly stated that lavas cannot be very hot because they solidify so quickly. Our experience, from observation is, that the hotter a surface of lava is, upon being exposed suddenly to radiation, the more quickly it will turn black, hard, and solid—in short into a black glass. A little reflection shows that this is a result to be anticipated. We need go no further for a practical illustration than the boyish experiment of using warm water instead of cold, to make a slide. If a thoroughly molten lava gets slowly and partially cooled, crystals begin to form, as a matter of course, which seems to injure its diathermanous qualities. The minute crystals appear to act either as a non-conductor, or as preventing radiation, so that a half-cooled surface of molten lava—and therefore in a partially crystallized state—will take longer to solidify, and probably to cool to the surrounding temperature, than a surface layer of a similar mass, suddenly exposed to radiation at a white heat. In the last case it will set quickly to a black glass, * but in the first case it will not become glass at all, that is, it will be partially devitrified. When observers speak of lavas cooling quickly, they usually refer to the visible surface layer.

A lava that will flash from a white-hot, molten state, to a solid black glass, hardly requires the hypothesis of being full of steam, to give it its apparent liquidity, and we do not hesitate to state our belief, from observation, that all Hawaiian lavas, before they have been accident-

* One of Professor Tyndall's lecture experiments is to illustrate the diathermancy of black glass, which is precisely what this quickly cooled lava crust consists of. This quality of allowing heat to pass easily is probably still greater in the *molten glassy* state, and may allow of a rapid radiation of heat to a certain depth, but which a partially crystalline condition, might destroy. See "Heat as a Mode of Motion," by John Tyndall, F.R.S. New York, 1872, page 326.

ally cooled by exposure and radiation, and so become semi-crystalline and viscous, and before they have also accidentally taken air or water into their composition, would instantly flash into a compact black glass, if suddenly spread out in a thin stratum, subject to free radiation. *

Hawaiian lavas, however, are constantly vesicular. Whole flows seem often to be a mass of glassy cells, and the basic pumice, (so-called) which is thrown into the air in immense quantities, with most great eruptions, is a congeries of glass cells, so light as easily to float in water. Besides, at the sources of eruptions, immense columns of vapors and smoke of all shades, from pure white to black, very frequently arise. How then can we disentangle the effects of these elastic vapors, and affirm the probability that on Hawaii, steam has comparatively little or nothing to do with the fluidity of the lavas, or with their cellular structure, or with their ejection from the orifices of eruption.

We would first remark, that a vast majority of the cells in Hawaiian lavas seem to be simply air bubbles, often containing, perhaps, partially deoxidized and contaminated air. The various modes of enclosing air, are palpable to any careful observer. In the lava lakes of Kilauea, what has been called the "boiling movement" acts like a Bessemer converter in filling the mass with air bubbles. We cannot conceive, however, that there

* The idea that water and steam is the main feature in causing the fluidity of *molten* lavas, may have arisen from the circumstance that very hot rocks, but under the temperature of fusion—seem to acquire an internal mobility of their particles akin to that of fusion, by the presence amongst them of water (or steam) under pressure. It seems probable indeed, that whilst under a high head of pressure even thoroughly molten, or superfused lavas might have their mobility increased by intermingled water. But the moment this pressure is relieved and the steam begins to expand, the expansion alone would rapidly reduce the temperature of the whole, and therefore, probably render such lavas more viscid. Thus Hawaiian lavas, without expanding steam, are "remarkably liquid," whilst Vesuvian lavas, which are noted for emitting steam, are "comparatively viscid."

is any true boiling, that is, the lava is certainly not being vaporized. It is—as a whole—being cooled, not heated. The movement appears to be simply the movement of convection currents, and to this extent analogous to boiling; just such a movement as we might expect to find in a large deep mass of excessively hot liquid which had its surface exposed to radiation and cooling, and to which a comparatively unlimited supply of new hot liquid was kept up from below. But this movement of convection is on a grander and more violent scale than anything else we are likely to observe in our experience with hot liquids. The molten lava seems generally to rise towards the centre of the lakes and go down at the sides. Wherever the lava is *going down*, there we find an almost constant jetting of the liquid in fiery spray and clots. The downward convection currents—as we interpret the facts—draw the air down with them, which becoming intensely heated in the white-hot lava, is rapidly expanded and converted into a highly elastic gas. It therefore, springs back again, bringing with it a portion of the molten lava, or often becoming entangled with an upward convection current it rises with the white-hot lava, and both appear in the form of jets, sprays and domes, which throw off pumice and Pele's hair. The proof that this jetting is caused by returning air is, that observation shows that the jets mainly occur at the parts of the lake where the lava is seen to be *going down*, often in whirl-pools, and at the points to which the general set of the surface currents tend. *

In the paroxysms however, of the action of the lakes —and these are often regular in their periods—whirl-

* We may call attention to the fact that even a gentle downward current in a liquid, will draw down considerable quantities of air, as may be constantly seen in the little whirl-pools in running streams. The convection movements of the Kilauea lakes, however, are rather to be compared in violence to the movements of rivers in flood, running under a bridge or large culvert, and when the level of the flood is above the crown of the arch.

pools will form anywhere on the surface, and the most violent jetting will be found at the main whirlpools, that is, where the cooled lava is descending. They will often start towards the middle of the lake, and generally work over with a very violent action, towards the sides and towards the usual jetting places—that is, towards the descending currents. The pieces of broken up crust are seen to tip on end and go down with the whirling lava, the molten spray being at the same moment thrown back, as immense quantities of air must be taken down at the same time. After one of the paroxysms, the lake usually cools over black and hard. Many of the rising air bubbles become fixed in the cooling crust.

But now, after a paroxysm, all has perhaps, become as still as death; a slight jetting from the side, may now and then occur, throwing clots of molten lava on to the blackened crust. On looking round at the sides of the lake, we now see that its level is as it were, at low water mark, and we notice two or three feet of the walls of the lake above the crust are red-hot. The whole lake has lowered during the paroxysm, as some would perhaps, say, by the escape of the vapors, but as we would suggest, by the lowering of the temperature of the lava, to a considerable depth, caused by the breaking up of the crust and exposure of the hot lava to radiation, as well as by the taking down and re-melting of large portions of the crust. * The lava has just been acquiring, not losing, elastic gases, (air) but it has been unquestionably, losing heat and consequent volume. †

* It will be unnecessary to urge upon physicists the powerful effect produced by melting a solid in a liquid in reducing the temperature of the latter.

† There must, however, be a certain amount of sensible heat developed in this process by the combustion of the elements of the air with the molten minerals and metals, forming for instance, magnetite with the iron, on the principle exhibited in the Bower-Barf process; but this heat must be small compared with the general cooling processes in action.

On watching the blackened crust of a lava lake, we shall now find that it gradually rises, especially towards the centre. The convection currents are gradually raising the temperature at the upper part of the column, which had just been cooled off. If elastic vapors were now accumulating under the crust, we ought soon to notice decisive evidence of them, for certainly none are escaping now. All is still. At last a crack may suddenly open with a ringing sound, across the centre of the hardened crust, by the pressure of the expanding molten lava below. We do not observe any outburst of vapors, but often a line of nearly white-hot molten lava squeezing quietly through the crack. But almost immediately a general commotion of the crust takes place, and it cracks in all directions. Jets, nay fountains of molten lava spring into the air, and the whirl-pools (lava descending) with their accompanying jets or fountains, work towards the sides, and great masses of crust go down in the whirl-pools. While we are looking for some new action, the surface freezes over and all is again still —only to repeat, however, in a short time, the same operation. These periods are usually very regular.

This may be called a common instance of what goes on at the Kilauea lava lakes, but the phases of the same principles of action are innumerable. Sometimes the surface of the lake may not set solid for days or weeks, but it will be constantly covered with a viscous skin of a grey satin shade in daylight, through which bright, blood-red streaks are seen, wherever the constant movement partially draws the skin apart, and reveals through these thinner places, what must be the white-hot molten lava, shining through and heating through, from below. There is then, often a continual movement in one direction, probably towards some white to red-hot cavern at the side of the lake, where it is evident the lava is *going down*, taking the air with it, but which air, becoming

intensely heated, continually flies back, bringing with it jets of the molten lava, which covers the advancing scum, and bespatters the red-hot roof of the cavernous opening, from which hang long lava stalactites, covered by the red dripping liquid thus thrown on to it.

It has sometimes been said that the large quantities of *pure aqueous vapor* often noticed in and about Kilauea, shows that it is steam, or the vapor of water, which produces the appearance of "ebullition" in the lava lakes. We venture to suggest that any vapor of water which had been intimately mixed or "boiled up," with the white-hot molten lavas of the Kilauea lakes, could never appear again at the surface as pure steam. It would be partially decomposed, and unmistakably tainted with sulphuretted hydrogen. Even the moist air which escapes would be so tainted. There is an evident source for all the pure steam found about Kilauea in the rain and the surface waters that get to the hot rocks; but they must be less hot than incandescent; or else the proportion of water to molten lava must be sufficiently great to reduce the temperature below a full red heat.

The eruptions on the side of Mauna Loa, many thousands of feet above Kilauea, are usually considered to be the result of a higher column of molten lava beneath the central and summit crater of Mauna Loa, (called Mokuaweoweo) although the lava may not always show itself in the summit crater.

The majority of these eruptions break out suddenly without earthquake, noise or explosion. The bright light has often been the first notification to those who dwelt nearest the spot, and which often comes up, to use the expression of an observer, "as quietly as a moonrise." The lava springs out of the ground in the manner of water from a burst water-pipe, or from an artesian bore when the water-bearing stratum is struck.

In all these eruptions which occur on the side of the

mountain, it can hardly be doubted that they are simply the result of the hydrostatic pressure from the head of lavas above them. In the eruption of 1840, the simultaneous lowering of the lava in Kilauea, was strong proof that this was the principle of the eruption in that instance. The fountain of lava, however, which played steadily for months, from the summit crater of Mauna Loa, in 1873, and which we had the good fortune to see, cannot be thus accounted for, but we shall refer to this point in the sequel, showing that the principle of these eruptions may have been hydrostatic pressure also. But our object in referring to them now, is to show that all these lavas are constantly cellular, that is, they become full of air bubbles. * Let us for a moment consider what would

* Prof. J. D. Dana, in an article on "Volcanic Action," in the *American Journal of Science*, Vol. XXXIII, February, 1887, cannot admit that air produces cells in lava. Referring to the facts at Kilauea, he observes: (p. 108) "The play of jets over the surface may serve to entangle some air, and add to the volume of the confined vapors. But air alone has very feeble expanding power when heated, and could not make cells in the heavy liquid, and much less make a scoria." Surely there must be some misapprehension here. Air alone has practically as much expanding power when heated, as steam alone, or as any gas *out of contact with its generating liquid.* Its power to produce violent explosions is well shown in Hawaii, when lava streams run over caverns in the arid districts. The principles exhibited in such explosions of heated air, are, however, merely an extension of those shown in the familiar operation of roasting chestnuts. With regard to air not being able to make cells in the heavy liquid, the air cells so common and so troublesome in iron and other metal castings, proves that the weight of the liquid does not prevent their formation. In the manufacture of common bottle glass, which is close to a basic lava in composition, the great difficulty is to avoid the inclusion of air bubbles. Indeed this is one of the troubles of the glass manufacturer, whether he attempts to make a beer bottle or a lens for a telescope.

An Hawaiian lava lake or lava fountain, is a great glass factory rudely worked by the blind forces of nature. What wonder then, that hundreds of acres near them are sometimes covered with glass foam, or congeries of glass air cells. The content of these cells should be water, with a partial vacuum, if they were produced by steam. Let them be carefully analyzed as soon as possible after they first fall. In a notice by Prof. Dana on Pele's hair, with analysis of same, published in the *Popular Science Review*, October, 1879, p. 428, and in the *American Journal of Science*, Vol. XVIII, p. 134. he speaks of it as frequently containing "air-bubbles," and refers to Krukenberg, who also analyzed it, and found "air-cavities" in it. Pele's hair always appears at these lava fountains, with the basaltic pumice, or glass foam, and the cavities in both forms of this volcanic glass are probably, therefore, of the same nature.

be the effect of a fountain of water rising through the ground from a burst water pipe under a high head, and during a frost so intense that the water froze almost as fast as it fell. Would not the resulting ice be full of air bubbles? Every little projecting point of the surface of the ground from which the water issues, becomes a means of impregnating the rising water with air bubbles, and if it froze immediately, the bubbles would often become fixed in the ice. This seems to be just the condition of these fountains of liquid lava.

Again, the fountains tend to form lakes of the same liquid around them, and as the spouting lava rises and falls in this lake, it must necessarily enclose immense quantities of air, which produce permanent cells as the lava cools and becomes viscous or solid. If even no air cells were produced at the fountain, (which, however, seems inconceivable) the moment the lava began its first rapid course down the slopes, rushing like a torrent over obstructions and down precipices, at first like a fiery river, and afterwards in a tunnel formed by its own cooled crust, it would enclose vast quantities of air bubbles. It is only necessary to look at a small rill of water pouring even gently, into a cistern, to notice what large numbers of air bubbles are taken down with the incoming stream and carried long distances under water. Waterfalls, fountains, and violent actions of a similar kind, convert the water below into a mass of foam. Basic lava foam is instantly solidified, when thrown into the air, into glass foam, which is precisely what our so-called pumice is. *

* This glass foam seems to be thrown up with the up-shooting lava, in spherical balls with a whirling motion. The centrifugal force, and the more rapid cooling outside seems to produce a hollow in the centre, which hollow is lined with a coating of glass. The small air cells also, often become compressed between the inner and the outer glass by the same force. We have sometimes noticed them with a lens to be distinctly polygonal, but fitting each other like soap bubbles blown in a bottle. We have never happened to pick up a complete sphere of this glass foam; it seems always to break in falling.

But it is said, and no doubt truly, of many lavas, that undoubted steam is constantly seen to escape whilst they are in the act of cooling. The Hawaiian lavas have indeed, been brought forward by Scrope, as illustrating his principle of volcanic action through the impregnation of lavas with water and the resulting steam, for he accidently, no doubt, misinterpreted the Rev. Mr. Coan's account of an eruption of Mauna Loa in 1852, to show that "From the surface of the lava current also, clouds of steam rolled up in fleecy wreaths towards heaven." * The Rev. Mr. Coan did not say so. The passage Mr. Scrope quoted from reads as follows:

"I have seen the igneous fusion pour all night long over a precipice of sixty feet, and I have also seen it fall over another thirty-two feet, into a basin of water, deep and large enough to float a frigate, whilst all night long clouds of steam rolled up in fleecy wreaths towards heaven." †

The clouds of steam did *not* rise from the surface of the lava current, as Mr. Scrope interpreted it, but from the surface of the basin of water, deep and large enough to float a frigate, and into which the molten lava had been pouring "all night long."

The late Mr. Coan, who was called here sometimes, the Bishop of Volcanoes, had been nearly half a century on Hawaii, and never lost an opportunity of visiting the great eruptions on Mauna Loa. He had probably seen more flowing molten lava than any man of his day, and being a gentleman of intelligence, and a thoroughly reliable witness in every respect, we took the liberty, in 1875, to address him a note, asking him to inform us as to what were the facts on Hawaii, with reference to the statements sometimes made regarding steam escaping from Hawaiian lava currents, and if he ever saw it so

* Volcanoes, by G. Poulett Scrope, F.R.S., F.G.S., second edition, London, 1872, page 476.

† Quarterly Journal of the Geological Society, XIII, page 170, 1856.

escape, except in situations where they clearly came into contact with water? The following is his reply in full:

"HILO, Jan. 27th, 1875.

"DEAR SIR:—Your esteemed favour of 25th inst. came to hand a few hours ago, asking my opinion whether liquified lavas ever generated steam unless in connection with water, which the fused or hot lavas evaporated?

"My reply is brief and in the negative. The flows I have witnessed in streams and basins of water, and in passing through forests of wet jungle, have of course, evaporated the water, sometimes with great rapidity, as *e.g.*, when a large river of incandescent lava falls into a water channel, or pours over a precipice into a deep large basin of water under a cataract. In such a case I have seen water deep enough to float a frigate licked up in one night and sent up in swirling wreaths of fleecy white into the air. And I have seen such a river of liquid fire cause the water to boil with great vehemence, raising bubbles of enormous size. But where a fiery stream flows over a dry surface, it emits no steam, and even mineral gasses are but slightly discharged, except from orifices out of which the lavas are discharged from subterranean fountains. Wherever we see aqueous vapours arising from fissures or vents in the strata of the earth, we may be sure that water and fire are in conjunction below. I hope, my dear sir, that in this very hasty reply to your note, I have made myself understood. Mokuaweoweo is still a roaring furnace in strong blast, but the action is all confined to the deep crater.

"With sentiments of kind regard, I am, dear Sir, most truly yours.

(Signed,) T. COAN."

William T. Brigham confirms this view and says speaking of the Kilauea lavas:

"The fusion is perfect as seen in the Pele's hair, and when the lavas granulate, they do so without any disengagement of vapor. I have seen the streams or rills of lava moving with such entire freedom from anything like smoke, that had I not been watching, they might have passed near me unnoticed. Wherever the melted rock passes over combustible matter, or through swamps, the vapor generated is sufficient to convert the surface and mass also into a porous rock. It must not be inferred that gases never inflate the lava in the crater." *

* Notes on the volcanoes of the Hawaiian Islands, by Wm. T. Brigham, A. M., Boston, 1868, from the Memoirs of the Boston Society of Natural History, Vol. I, Part 3, Page 461.

He then briefly refers to the cellular pumice, glass-foam or "*limu*," the origin of which, from the entanglement of air, we have already endeavored to explain.

In 1859 we climbed on to the top of the slaggy walls of one of the *aa* streams of the eruption on Mauna Loa, of that year, and down the centre of which the molten lava was flowing in a steady stream. It was partially crusted over. This crust, within about three feet of where we stood, was nearly black by daylight, and moving quite slowly, but the color graduated through a cherry-red to a full red heat in the centre, which was perhaps forty feet from us. Here the speed of the viscous crust increased to four or five miles an hour. Underneath it was evident that the lava was very much hotter, more liquid, and running much more rapidly, as we very soon had ample proof. For while we were standing looking at the sight, our companions on the old lava below, called our attention to a thin stream of nearly white-hot molten lava which, passing underneath our feet, had broken out in the scoria wall about a yard above the surface of the ground (old lava) and was pouring from the opening precisely as a stream of molten iron runs from a furnace.

We made our way down, a few yards above the outflow, for fear of being cut off, and stood for nearly half an hour watching the action of the outbreak. The molten matter seemed quite as liquid, and purer than molten iron from a furnace, for this often emits sparks.

Even when we were on the top of the scoriaceous side walls of this molten river, not the slightest suspicion of steam or vapor could be noticed. Not even a whiff of what Mr. Coan called mineralized vapors, although the light air that there was, came towards us. A peculiar tremulousness in the atmosphere over the heated parts of the stream, was however, visible by careful observation, in certain lights. This appeared to be the same effect

which is often noticed over hot *dry* sand, and was probably the result of the same cause; namely, the convection currents of heated and cooler air mixing, when the excess of moisture, held by the heated air suffers condensation on mixing with the cooler currents.

We should, perhaps, remark that the old lava in this region of the mountain is usually excessively dry. Not a drop of water being obtainable for drinking in two or three days' travel, unless when the snow happens to lie on the top of the mountain; and even then there are no streams in this region, and one has to go to the snow itself for water.

The outbreak of lava which we have referred to from the side of the *aa* stream, quickly formed a considerable surface of hot *pahoehoe.* The same day we traveled some distance down the side of this *aa* stream, and found several places where the *pahoehoe* was running out from it in a more or less molten state and covering a considerable area of ground. Towards the evening, whilst at one of these places, a Scotch mist rolled up the mountain. As the water drops fell on the hot iron-lava the smell of a gas-works became immediately perceptible; or rather, perhaps, the smell which is noticed in a blacksmith's shop when red-hot iron is plunged in water. The iron in the lava had decomposed the drops of water, and the so-called sulphureted hydrogen was the result.

We shall refer again in the sequel, especially in the Chapter on Hawaiian Volcanoes, to the subject of steam or elastic vapors in connection with volcanic action. Our object is not to show that steam does not act in certain volcanic eruptions, because it is well known to do so, and the hypothesis we are advocating, that water and steam are probably the main instruments in the local conversion of basic rocks—whether molten or solid—to acid rocks, requires it to do so constantly.

What we mainly wish to contend for, and to impress upon geologists—for re-consideration at least—is, that it may be a mistake to assert, as is so often done in the most positive manner, that water and steam are inseparably connected with volcanic action. On the contrary it would appear that elastic vapors have nothing to do with the liquidity of the Hawaiian basic lavas, and that as a matter of fact they do not seem to come up with them from below, whilst the basic minerals themselves give no indications in the main eruptions, of having been in in contact with water, highly susceptible as they are, to such an influence. The great columns of lava *standing for years*, many thousand feet above the sea level, cannot have been kept in that position, and probably therefore, were not brought there, by the agency of steam or elastic vapors. * The weight of the thin cooled crust, resting on the basic substratum, may be amply sufficient to account for the existence of molten lava standing permanently at these altitudes.

But we are not confined to the evidence of Hawaiian active volcanoes to show that inflation by steam is not necessarily or mainly; the cause of the rise of the lavas. Almost all the great dykes and intrusive sheets of the world are basaltic, and are very slightly, or not at all cellular. Indeed, these old dykes and their offshoots,

* The small degree of importance to be attached to the quantities of pure steam and steam jets in the Crater of Kilauea, may be gathered from a remark by Mr. J. S. Emerson, in his report to Professor W. D. Alexander, Surveyor-General of the Hawaiian Islands, and published in the *American Journal of Science*, February, 1887. He observes, p. 91: "Of steam jets in Kilauea, the number was very variable, and seemed to depend greatly on the condition of the weather and the hour of the day. At times, especially in the morning, the whole crater was almost entirely free from them, while after a shower of rain, particularly in the afternoon, they were very numerous, and with the mist which often accompanied them, rendered the work of surveying impossible." Water in a rainy district, gets to the hot rocks in all sorts of ways, about which there need be little mystery. All this steam seems to have no further connection with the forces concerned in the action of the lavas in Kilauea, than the vapors which arise from the body of a hard worked horse when a shower of rain has fallen on him, have with the force he exerts in drawing his load.

and what have latterly been termed "fissure eruptions," as well as laccolites, which proceed from the dykes, are now generally admitted to have been "squeezed out," or to have been injected or extravasated by a non-explosive force. Dr. A. Geike, referring to the great lava-floods of the Pacific slope of North America, says:

"Resting hour after hour among these arid wastes, I became convinced that all volcanic phenomena are not to be explained by the ordinary conception of volcanoes, but that there is another and grander type of volcanic action, where, instead of issuing from a local vent, whether or not along a line of fissure, and piling up a cone of lava and ashes around it, the molten rock has risen in many fissures, accompanied by the discharge of little or no fragmentary material, and has welled forth so as to flood the lower ground with successive horizontal sheets of basalt." *

Again in his Manual of Geology, he says:

"It is chiefly basaltic rocks, however, that in all parts of the world have escaped in fissure eruptions and now build up vast volcanic plateaux. The fragmentary Miocene plateau of the British Islands, the Faroe Islands and Iceland; those of the Indian Deccan and of Abyssinia, and the more recent basalt floods which have closed the eventful history of volcanic action in North America, are notable illustrations of this type of structure." †

We would venture to add the Hawaiian Group of Islands as an instance of a recent basalt flood, or succession of fissure eruptions, remaining open where certain fissures intersect, and still in course of being "squeezed out," for it will hardly be now contended, as Mallet did, that the basalt of the old dykes of the world was injected into the earth's crust, or poured over the surface as lava

* Gelogical Sketches at Home and Abroad, by Archibald Geike, LL.D.. F.R.S., London, 1882.

† Text Book of Geology, by Archibald Geike, LL.D., F.R.S., London, 1882, page 565.

floods, on an entirely different principle to that which raises the lavas in volcanic ducts, like those of Hawaii to-day. He called the first force hydrostatic, and the last explosive, and imagined the first force to have ceased somewhere about the Tertiary period, about which time also, he assumes the crust of the earth to have changed from being very thin to very thick. Having admitted the hydrostatic principle, what theory seems simpler and more consistent, than to consider the explosive phenomena added in many cases to the hydrostatic. That is to say, whenever the hydrostatic force lifts the lavas into a situation near to or above the surface, where large quantities of water, fresh or salt, gain access to them, explosive action may take place, and tufas and other products of the mixture occur. It is well known to geologists that these evidences of explosive volcanic action are commonly found in the oldest strata, but evidently as a secondary, or parasitic result, if the hydrostatic principle be admitted as the cause of fissure eruptions. *

But although the intervention of water and steam seems not at all necessary to account for the phenomena connected with the basic lavas—the cosmical rocks—and the acknowledged lower stratum of molten matter—just in proportion as lavas depart from the basic character and become acid or silicated, so water seems more and more likely to have played a prominent part in their development. M. Delesse says on this point:

"En resume, le trachyte present bien les caracteres d'une roche ignee; il a ete fondu ou tout au moius

* The great dykes on the Hawaiian Islands, of feldspathic basalt, "without a trace of a cellule," have always seemed conclusive to our minds—coupled with all the other facts connected with them—that these lavas were not raised to the position they occupy, either by explosive action, or by the more quiet expansion of occluded water; but having been lifted when molten, by hydrostatic pressure, and having never been exposed to the atmosphere, there are no air bubbles in them; and that in our view explains, at the same moment, their position and their compactness. Thousands of tons of specimens of this remarkably compact volcanic rock are to be found in *situ* about the group. See also Chap. IV, Section 2.

ramolli et rendu plastique par la chaleur. Mais lorsquil se charge de quartz, on voit succesivement ses caracteres distinctifs s'attenuer or disparaitre et il passe insensiblement au porphyre quartzifere ; tout port a croire qu'alors la chaleur joue un role de moins en moins important dans sa formation." *

Baron von Richthofen, whose broad and philosophical views on the distribution of volcanic rocks, have been found to be remarkably in accordance with new facts, as discovered in recent geological surveys in different parts of the world, says, regarding his first order of volcanic rocks, rhyolite or quartziferous trachyte, the most completely silicated volcanic rock:

"It is one of the characteristic features of rhyolite, that it presents, more than any other rock does, signs of having been in a state of what Daubree has called 'aqueous fusion,' or the fusion of its mass by solution under great pressure in super-heated water. Another peculiarity is the circumstance that the eruptions of rhyolite, whether massive or volcanic, bear evidence of having been generally accompanied by extremely violent solfataric action, which probably surpassed on an average, that connected with the ejection of other volcanic rocks. This action appears to have been one of the chief agents in the formation of the rich silver-bearing veins of Hungary, as well as some in Mexico, and to have also been peculiarly characterized by the occurrence of an unusually large amount of fluorine and chlorine, among the escaping gases." †

Again he observes, speaking of the "endless varieties of rhyolite:"

"A considerable influence, which has not yet been investigated, is probably exercised by the difference in the

* Recherecbes sur L'Origne des Roches Par Delesse, Paris, 1865.

† Principles of the Natural System of Volcanic Rocks, by F. Baron Richthofen, Dr. Phil. Being a Memoir presented to the California Academy of Sciences, page 13.

amount of water which entered into the composition of the molten mass, and partly expanded to steam at the instant of ejection. The vesicular inflation proper to trachytic texture, the spongy inflation of pumice stone, and the concentric separation of infinitely fine laminæ as is often shown in perfect pearlitic structures, are probably three different modes of manifestation of one slightly varied cause, which may most likely be found in the conversion of water into steam, which participated in the composition of the molten mass." *

Richthofen's next order of volcanic rocks, trachyte, is, he observes, "only inferior to rhyolite in the number of its varieties." * * * "The rock appears to contain, on an average, from sixty to sixty-five per cent. of silica, and is in this respect, as in others, next allied to rhyolite." * * * "Like almost all volcanic rocks, trachyte consists of a paste, in which are imbedded various crystalized minerals. This paste is of various colors, and has usually a more or less vesicular texture, which by its property of imparting to the rock a certain roughness of touch, gave origin to the name." * * * "Foliated structures may frequently be met with; but the folia are not of that exquisite fineness which is peculiar to those of rhyolite." †

Thus Richthofen's two orders of the acid or silicated volcanic rocks, are believed by him to have been in a special manner subject to the action of intermingled water and steam while in the molten state, and the more silicated order, the more so affected. His next three orders of volcanic rocks, propylite, (volcanic diorite?) andesite and basalt, belong to the intermediate and basic divisions of volcanic rocks.

M. F. Fouque, in his valuable and elaborate work, "Santorin et ses Eruptions," ‡ has especially referred to

* *Ibid*, page 14.
† *Ibid*, page 19.
‡ Paris, page 314, and on.

the probable action of imprisoned water on basic lava in fusion, as exhibited by the formation of trydimite opal, sphœrulites, and sphœrulitic concretions, so far confirming, by careful microscopic and chemical examination, what was suggested as probable, on general considerations, by Von Richthofen, that rhyolites were specially the result of the action of water on molten lavas. How, in fine, the action of imprisoned water in a molten basic lava, may ultimately result in producing an acid lava. The chapter on the submarine lavas of Acrotiri indicates how, an anorthite, or a labrador basalt, or an augite-audesite may be converted by this action into a silicated hornblende-audesite, or even into a rock on the verge of a liparite or of a rhyolite. This is the "promorphism" of some writers, although it may be often difficult to ascertain exactly how much change the water may have produced before and during, and how much after solidification, for zeolites seem to be usually the result of the percolation of water through the rock after solidification. The Acrotiri silicated basic lavas—if we may be allowed to use so equivocal an expression—and referred to dacites by M. Fouque * seem to be the result of changes caused by water on a basic lava in fusion, as well as during, and after its consolidation. The facts lead to the inference that a quartz-rhyolite may be the ultimate term of the action of superheated and compressed water on a molten and originally anhydrous basalt.

M. Fouque in this work, makes an incidental remark with reference to the apparent lower temperature of the acid lavas of Santorin, which seems to have an important bearing on the question of their origin. He observes: † "We should add that at the moment of their emission, the acid lavas would appear to have possessed

* *Ibid*, chap. 8, page 341, and on.

† *Ibid* page 316.

a temperature less elevated than the basic lavas; for otherwise it would be difficult to understand the fragments of basic lava in the midst of acid lava, which is less fusible. In supposing these two categories of lavas may proceed from the same subterranean furnace of constant temperature the more elevated temperature of the basic lavas at the mouths of the orifices of emission, is explained by their greater mobility and their greater conductibility of heat."

Without offering an opinion as to how far this explanation may help to account for the lower temperature of the acid molten lavas on their emission at the surface of the earth, we would venture to suggest, that on the principle here advocated, of their having been in most cases, the result of the access of water to molten basic lavas, this comparatively lower temperature would be one of the necessary results, not only of the first mixture with external water, but more especially of the expansion of its vapor on the relief of pressure, as the lava escaped at the orifice of eruption, whilst the more complete aqueo-igneous fusion when under pressure, and the mobility of the particles down below—would offer every facility for their solution, and the chemical re-composition which is assumed to have taken place. The great viscosity of the acid lavas on eruption, whilst we know that they must possess a higher temperature than the basic lavas at the purely igneous fusing point, has always seemed a difficulty, which however, the commonly admitted condition of aqueo-igneous fusion will in their special case, explain. Purely basic lavas, on the other hand, which retain their liquidity so long after emission, when protected from radiation, cannot be thus permeated with condensed and expansible gases, as the result would be rapid cooling and viscosity, as they neared the surface on the relief of pressure, even when not exposed to radiation.

We have endeavored to show, from independent data, that in the Hawaiian ultra-basic and highly fluid lavas; the condensed water and the resulting expanding steam sometimes attributed to them, are, as a rule, not there. Now we see, that if they were there, this lava would not long remain fluid, but would become viscous on relief of pressure.

It is worth noting here, that Baron von Richthofen makes the two classes of rocks, rhyolite and trachyte, with sanadin—the acid lavas—quite subordinate, both in mass and position over the whole globe to the more basic lavas. He says:

"As regards geographical distribution, trachyte is as much dependent upon, and as closely allied to, the pre-existing masses of Propylite and Andesite (semi-silicated or semi-basic lavas), as is the case with rhyolite." * * * "Trachyte does probably not compose, by itself, any extensive mountain ranges, and it remains in general, greatly inferior in bulk to Andesite. In Europe, its outbreaks were scattered and isolated, and, though they have been quite numerous, the aggregate quantity of trachytic rocks is not considerable." * * * "Specimens of trachyte owing to their beauty and varied aspect are usually much more numerous in geological cabinets than those of andesite—a fact which has frequently occasioned some misconception regarding the relative proportion and importance of trachyte and andesite among volcanic rocks."*

In this view as to the relative bulk and importance of basic over acid volcanic rocks, Richthofen is confirmed by many geologists; Dana says, in agreement also with what we have quoted above from Geike:

"A doleritic or basaltic character is the prevailing one among the igneous eruptions of all ages from Ar-

Ibid, page 19.

chæan time to the present, and of all continents and oceans."*

These general statements are confirmed in detail with regard to the late Tertiary volcanoes of Italy. Dr. Johnston-Lavis, in a recent article on Vesuvius and Monte-Somma, observes:

"Those geologists who have studied the late Tertiary volcanoes in Italy have always remarked a great similarity between their products. True it is that we have basalts, dolerites, leucilites, audesites, trachytes and rhyolites; yet the great majority of them range between the dolerite and non-quartziferous and rather basic trachyte, whilst the basalts and quartziferous lavas are confined to small and isolated patches. The remarkable similarity presented by the leucitic rocks in a range of volcanoes parallel to the mountain axis, and therefore bursting through similar strata, is worthy of notice. Perhaps not less so than the fact that all the smaller volcanoes that have been formed chiefly by spasmodic or paroxysmal eruptions are of the trachytic type or phonolitic at the most, whereas those of more permanent activity, as Etna, Stomboli, Vesuvius, Roccamonfina, and some of the Roman ones, have a much more basic character." †

When we consider the lavas and crystalline rocks intermediate between the acid and the basic classes, we find in them a new set of minerals which hardly exist, or at least are not typical, in the extreme types of either class; thus hornblende may be said to be absent from typical granite and from rhyolite, and from recent ultrabasic lavas. Neither is it found amongst the minerals of meteorites. If Bischof was correct, as recent researches seem to indicate, that hornblende is invariably a secondary product formed from augite, we should under-

*American Journal of Science, August, 1873, page 110.

† Geological Magazine, July, 1885, page 305.

stand how it comes to occupy the position which Durocher assigns to it of the transition mineral, always bearing in mind that when it occurs in a recent lava, it may be the result of aqueo-igneous fusion, and still therefore a secondary mineral, the product of the action of water or steam on augite. Following out Bischof's views we should explain the absence of hornblende from typical granite by its ultimate conversion into mica, a mineral now universally admitted to be, as Bischoff also contended, always the product of metamorphism, and which Jukes long ago considered to be a form of mineral rather than a distinct mineral.*

Just as granite may often be the product of metamorphism through the intervention of water, by which a solid basic lava may be ultimately converted into a rock consisting of an entirely new set of minerals, namely, quartz, orthoclase and mica, so probably the same basic lava in a molten state may be converted into an acid lava by the agency of heated water or steam under pressure, or to a quartziferous trachyte consisting of quartz, orthoclase (sanadin), black hornblende, and black mica, which minerals however, always present, when found in recent lavas, a peculiar appearance and lustre, and which indicates a difference between the mode of their formation, and the formation of the analogous minerals found in granite. The close analogy however in the character of the minerals in the granite—admitted by some petrologists to be sometimes a thorough transmutation of the minerals of basic rocks† with the character of the minerals in the acid molten lavas, thus assumed to be transmuted from basic molten lavas, seems to be a consideration of much importance.

* The Student's Manual of Geology, by J. Beete Jukes, M.A., F.R.S. Edinburgh, 1887, page 186.

† Handy Book of Rock Names, by G. Henry Kinahan, pages 52, 53, where he shows the probable conversion of whinstone to diorite, syenite and hornblendic granite. London, 1873.

We seem also to have an instance of basic molten lavas in process of transmutation towards the acid class, in the ejections from Vesuvius, and to the molten lavas of which, it is generally admitted, that sea-water gains access, whilst steam, chlorides, and other products of the evaporation of sea-water are seen to escape from them.

Durocher, who, however, looked upon the acid and basic lavas as proceeding from two originally distinct magmas, observes of the Vesuvian lavas:

"In a chemical point of view they differ little from doleritic lavas, (composed of labradorite and pyroxene) except by a less proportion of oxide of iron," . . (losing bases) "and by the abundance of soda which appears due to the intervention of sea-water." *

Haughton and Hull in their report on Vesuvian lavas, refer to the frequent presence of free quartz in them, and say:

"It would therefore appear that in such cases the lava must be considered as on the margin of the acid series as distinguished from the more general basic varieties."†

Rutley says of them:

"The leucito-sanadine lavas of Vesuvius have, as a rule, such a very complex mineralogical constitution, that they cannot be regarded as the equivalents of basalts." ‡

All the evidence then, goes to show, that these Vesuvian lavas are acquiring quartz, and sanadin, and losing iron, under the action of intermingled sea-water. The very detailed report of Messrs. Haughton and Hull, with plates of magnified sections, leads towards the same conclusion, with this remarkable apparent anomaly, that they refer the triclinic feldspar to anorthite, the most

* Manual of Geology, by the Rev. Samuel Haughton, M.D., etc., etc., London, 1871, page 32.

† Transactions of the Royal Irish Academy, vol. XXVI, Dublin, 1876, page 158.

‡ The Study of Rocks, by Frank Rutley, F.G.S., London, 1879, page 256.

basic feldspar, rather than to labradorite, which, however, may very probably be the result of these lavas rising through limestone strata, so that the undue proportion of lime may convert the labradorite to anorthite, an effect which has been noticed in other, but analogous cases.*

The experiments of M. Daubree † show that the action of super-heated water, or steam under pressure, on a basic non-crystalline glass, is to produce perfect crystals of quartz, and crystals appearing like orthoclase or sanadin, the characteristic minerals of rhyolite, as well as diopside and other minerals constantly found in the more acid lavas, trachytes and trachy-dolerites, but seldom in ultra-basic lavas, such as those of the Hawaiian Islands, unless possibly, in certain situations where water has had access to the molten matter.

All the main rocks forming the crust of the earth, except a few organically formed, may be comprised under the head of basic or acid; and if the acid can fairly be assumed to have been developed from the basic through the intervention of the ocean, as Daubree suggested, that is, by the action of water (and its contained carbonic acid mainly) upon the molten and solid basic rocks; the answer to the question, what is volcanic matter, becomes much simplified, for then almost all rocks would be the interior basic magma, or the same, more or less modified and silicated by the action of water and the atmosphere.

Jukes and Geike, in their Manual of Geology already quoted, say on this point:

"The identity or very great similarity of the various

* The Student's Manual of Geology, by J. Beete Jukes, M.A., F.R.S., Edinburgh, 1857. Granite "having its feldspar changed from an orthoclase, p. 276, which was the feldspar of the granitic mass, into anorthite, in consequence of the addition of the lime which it had taken up from the limestone.

† Etudes Synthetiques de Geologie, Experimentes par A. Daubree, 1879, page 150 and on.

volcanic products in all parts of the world, seems to point to a common origin for them. The frequent association, in all parts of the earth, of the two great classes of these products, the trachytic and doleritic seems to show that their difference is not so much due to diversity of origin, as to some cause tending to segregate the one from the other, out of a generally diffused mass. The association of felstones and greenstones among traps seems to be reproduced in that of trachyte and dolerite among the lavas." *

If then this view be correct, that all the main rocks of the earth's crust may have been developed from a universally diffused basic magma, we ought to find in the ultra-basic lavas, nearly all the elements of which the great mass of the earth's crust is composed, to which, however, have been added water and the elements from the atmosphere and their compounds. We ought to find those elements also in the ultra-basic lavas, in relative proportions, commensurate with the proportions in which we find them to exist in the earth's crust generally. Further, we should be able to show with some degree of probability, that, descending to details, all the great classes of rocks and minerals, except certain organically derived ones, not only may, but often do, proceed from a basic lava, or an olivine-basalt. †

In this view of the origin of the acid granitic rocks, it does not seem necessary, in the meantime, to either affirm or deny the possibility that some of the lowest granites, gneisses and schists, may have first consolidated from fusion, as a sort of "ecume siliceuse," in the mineralogical condition in which we find them in the Archæan ‡—or as M. de Lapparent terms it—the "Terrain

* Page 349.

† On the elements contained in olivine-basalt. See Appendix.

‡ The gneiss and crystalline schists of the Archæan, seem to have possessed their distinctive crystalline and metamorphic character in

Primitif," for it seems more than probable that whether they first so consolidated or not, to this complexion may an ultra-basic crust arrive, by the action of water and other dissolvents, and the atmosphere. It seems probable also, that whatever thickness of these first consolidated acid rocks may have once existed, the quantity of basic matter which has flowed into them and over them has been vastly greater, and that the basic rocks have at one time or other formed the mass of the earth's crust. Granite and the acid rocks seem to be those which have been deprived of the basic elements which make up the mass of the earth's crust above them, and which, from every indication appear to exist below them.

Let us consider for a moment, one element, calcium, or rather the mineral carbonate of lime. Is it possible that an ocean like the Pacific could have developed the enormous masses of coral reefs, of globigerina ooze, and other organic deposits of carbonate of lime, unless the lime had been furnished by basic volcanic ejections, either on the continents surrounding it or in the ocean itself. Such an ocean, entirely surrounded by continents of granite rocks, with islands only of granite, and with no basaltic volcanoes, certainly could not have furnished lime enough, for this is the substance which almost entirely disappears from the minerals of typical granite and the acid lavas. *

Archæan times, as is evidenced by pebbles of the gneiss being found in succeeding, but nearly unaltered strata of the same epoch. This indicates that the long period of the subsequent epochs was not required to produce a thorough metamorphic character in these rocks, and favors the view often advanced by geologists, that the conditions under which these earliest formations were developed, may have been different—in degree if not in kind—to those existing subsequently. A very hot and moist atmosphere, with possibly an excess of carbonic acid, and a greater depth of the whole atmosphere, and consequent greater pressure, are condidions that probably existed in that period, and at the same time they are such as would be calculated to rapidly disintegrate and decompose the basic crust which may have then appeared above the ocean.

* "If the river drain a country composed of hard and almost insoluble rocks, the water will contain but little mineral impurity. Thus

This question seems important and pertinent to the general enquiry, for it suggests that the immense mass of coral reefs of the earth, as well as all the organic limestones and marbles, may be to this extent, basic volcanic products. That is to say, that the lime has been furnished, in the first instance, by the basic igneous rocks and lavas. The silicates of lime have been dissolved by, and the lime has united with, the carbonic acid of the atmosphere, and been carried by the usual processes of erosion, degradation and denudation, into the ocean as carbonate of lime, there to be appropriated by organized creatures and turned into rock, shell, bone, or other solid matter, as fast as it arrives; for the small proportion of carbonate of lime, in a state of solution, in the ocean, is remarkable.

Thus when we speak of coral reefs, globigerina ooze and limestones, as organically derived rocks, or deposits, we only mean, that they occupy their present position through the instrumentality of organization. The material may be essentially volcanic. The atmosphere has added to it, whilst rain, rivers, and organized creatures, have united in segregating it in the deep ocean beds. *

The late J. Clifton Ward, of Her Majesty's Geological Survey, seems to have struck the key-note of the theory of the origin of rocks, in the first paragraph of an article on the Lower Silurian Rocks of the English Lake District. He says:

"The Volcanic Rocks of the lower Silurian Age in the Lake District, are interesting in the highest degree, on many accounts, and not least so on that of the extreme metamorphism which they have undergone, partly by the deep burial they suffered during the period between

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the water of the Dee, of Aberdeen, which derives its supply from a granite district, contains only about three grains of saline matter in a gallon." Physiography, by T. H. Huxley, F.R.S., London, 1879, page 125.

* From this point of view, basic volcanic ejections assume a position of paramount importance in considering the history of our globe.

the close of the Lower Silurian and the old Red, when they were once more largely uncovered, and partly by that never ceasing action of infiltration, decomposition, solution and replacement to which all rocks are subject during the course of geological time, but to which rocks of an originally volcanic origin, seem especially subject." *

This special illustration, may perhaps, be generalized thus: All rocks are primarily of volcanic or igneous origin, that is, either irruptive or eruptive. The minerals originally composing them having been screened from the chemical action of the elements of the atmosphere, in the depths below, are specially subject to their influence, when exposed to them. Those crystalline rocks, not now termed volcanic, are merely those originally igneous ejectious, which by infiltration, decomposition, solution and replacement of the elements of their component minerals—and often after mechanical erosion, degredation and reassortment—*have suffered* a course of changes through atmospheric influences, and therefore, by a well known chemical law, are less subject to new ones. Whatever changes minerals have thus suffered, must have been from the unstable to the stable condition.

Thus, the three highly mutable minerals, olivine, basic feldspar and augite, which mainly form the stony portion of the meteorites which arrive from the depths ot space, and which also compose the great mass of lavas which are ejected from the lowest depths, beneath the earth's crust—protected in such situations from chemical action—largely disappear in the oldest and lowest strata, having then been long subjected to atmospheric influences, either in early periods, when they were more powerful, or in their progress through the geological ages

* Mineralogical Magazine, No. 4, April, 1887, page 119.

towards that position. In their stead we find minerals remarkable for their permanence, and little affected by such influences, namely, quartz, orthoclase, potash-mica and serpentine. These minerals are not only shown by mineralogists, to be the result of the action of the atmosphere and water on other minerals, but have often been traced as products of the alteration of olivine, labradorite and augite. The existence therefore, of the derived but permanent minerals, quartz, orthoclase and mica, mainly in the lower layers of the earth's solid crust, seems to be another, but comparatively simple case, of the modification of species by the environment under general laws, and the survival of the fittest—that is, the fittest to endure. *

So far we have referred mainly to the two classes of minerals at the extremes of the series, but there are intermediate rock-forming minerals which should fall into their places on the general hypothesis of the evolution of all rocks from a universally diffused ultra-basic magma.

Hornblende, as already observed, has been called the transition mineral, and has given its name to a series of rocks which have been considered intermediate in time, position and constitution, between dolerite and granite, and of which the diorites and syenites are the principal.

Although equally absent from typical dolerite and typical granite—the two classes at the opposite extremes of every classification of rocks—hornblende is the characteristic mineral of the intermediate classes. If we are

* If we may suppose that, in accordance with the general theory, sanadin and the leucite group of minerals are formed from the plagioclase basic feldspars, by the action of steam on molten basalt, and possibly in connection with the strata through which it rises—we see a reason for these being such fugitive minerals when exposed to ordinary atmospheric metamorphic action; for they have not been subjected to such an action during the process of their formation. These minerals disappear in the old strata, being usually found converted into the ordinary feldspar of granite. They seem, notwithstanding, to affect a composition which may be termed metamorphic, in possessing potash instead of soda for the alkali.

warranted in following Bischof, who did not hesitate to say, "taking all the facts into consideration, there is probably not any single ground for supposing that hornblende is formed from fusion, * and may believe that it is always a transmutation mineral, usually formed from augite; hornblende may be looked upon as the great connecting link in the chain of evidence showing the evolution of the silicated rocks from the basic volcanic rocks. It becomes the key to the position, and as the universal intermediate mineral in a general system of transmutation, should help to unlock the secrets of mineralogy and render invaluable assistance in developing a natural system, both of minerals and rocks. It would, as a transmutation mineral, indicate not only that there has been a general system of mineral evolution, but it points out the particular direction of it."

Lyell, in his Principles of Geology, as far back as 1832, said:

"Hornblende, which is so common in ancient rocks, is rare in modern lava, nor does it enter largely into rocks of any age in which augite abounds." †

Recent researches have so far modified this statement that in those cases where augite and hornblende are found together, the one is commonly seen to be changing into the other. Indeed, Lyell's Student's Elements of Geology, dated 1874, speaking of hornblende rocks, says:

"Some of these hornblendic masses may really have been volcanic rocks which have since assumed a more crystalline or metamorphic texture." ‡

But the constant alteration of augite to hornblende on a large scale has been so fully sustained, that it will only be necessary to refer to a few of the papers where

* Chemical and Physical Geology, by Gustav Bischof, vol. II, London, 1855, page 343.

† Page 453.

‡ Page 548.

an account of the change has been recorded.* Mr. G. H. Williams' paper is especially definite and to the point.

R. D. Irving, in a paper on the Origin of the Hornblende of the Crystalline Rocks of the North-Western States, in the American Journal of Science, July, 1883, concludes his article as follows:

"Thus, after an examination of about a thousand thin sections representing the crystalline schists, acid eruptives, and basic eruptives of a region some 400 miles in length by 300 miles in width and of three distinct geological systems. I have found no hornblende that is not either clearly, or very probably secondary to augite." †

When we find that hornblende, as a rule, appears in the place of augite as we proceed from the newer to the older rocks, besides being found so constantly changing from it,‡ we need hardly remain longer in doubt that Bischof's view was correct, that hornblende is invariably the product of transmutation, and usually from augite. It need cause no difficulty that augite should sometimes be found in older rocks than hornblende, for it may easily occur that the circumstances necessary for the change may not have existed in certain strata or certain parts of them. The fact also that hornblende is sometimes

*G. H. Williams' Am. Journal of Science, October, 1884.

J. A. Phillips' Quarterly Journal of the Geological Society, May, 1878, page 168, and August, 1878, page 493.

Ward Quarterly Journal of the Geological Society, February, 1876, page 28.

Heddle Mineralogical Magazine, October, 1879.

† Page 32.

‡ Mr. R. D. Irving has written a supplementary paper in the American Journal of Science of February, 1884, on the "Paramorphic Origin of the Hornblende of the Crystalline Rocks of the Northwestern States," in which he shows that other lithologists had arrived at the same conclusion, and says: "In this study not only did we find that all of the hornblende of the greenstones examined (including gobbro, diabase, diorite, etc.,) was secondary to augite, but also all of that of the hornblendic gneisses, hornblendic schists, syenites and hornblende granites. Since the paper above alluded to was printed, we have examined many more sections from the Archæan rocks, from Lake Huron to the Mississippi, and have thus far found nothing to change our views."

ejected at the present day by trachytic volcanoes, is probably merely evidence that the action of water and steam on the elements of a molten augite may produce hornblende. It is not usually ejected by modern active ultra-basic volcanoes.*

It seems well worth noting that in the transmutation of augite to hornblende, the most prominent change is in the same direction as that which we have already noticed between dolerite and granite, namely, in a loss of lime. Again, what are called the alteration products of augite show the same change—that is, they show progression towards hornblende by a loss of lime.

The microscopical examination of thin sections of rocks has led Allport and others to the conclusion that diabase, melaphyre, and other trap rocks, are partially altered dolerites, and they seem to begrudge them new names, although new minerals, especially chlorite, make their appearance in them. When they arrive at diorite, however—as in this rock the traces of the changing minerals are often lost—they readily grant a new name and call the minerals composing it primary, not secondary, minerals. We have already seen, however, that the weight of evidence is now in favor of hornblende—the characteristic mineral of diorite—being always of secondary origin, and usually formed from augite; and as the plagioclase feldspars of diorite usually belong to the more silicated feldspars, there can hardly remain a doubt, that we may go a step further than the microscopists have actually led us, and believe that diorite is a more complete stage of the alteration of dolerite, so fully corroborating the view long ago taken by Allport, who concluded a paper on the "Igneous Rocks," published in the *Geological Magazine* of 1871, as follows:

* Augite, in the more recent volcanic eruptions, and hornblende appearing in its stead in the more ancient, is such a commonly recognized fact, that it is unnecessary to give quotations.

"But it is already tolerably clear that the difference now found to exist between the so-called *Plutonic* and the volcanic rocks is due to the metamorphic action to which the former have been exposed during the long periods which have elapsed since their original formation."*

Bischof long since warned mineralogists that they must not conclude that a mineral is not a transmuted one because it shows no evidence of the change or of decomposition, and that the minerals of no rock are more perfect, and apparently unaltered, than those of granite, but which are now generally admitted to be the result of metamorphism.†

But a diorite approaches closely to a syenite, and the substitution of orthoclase for oligoclase or albite, would complete the metamorphosis; indeed, many syenites contain oligoclase as well as orthoclase. A diorite again, with quartz and mica, approaches a granite, whilst the distinction between a hornblende granite and a syenite is

* Geological Magazine, Vol. VIII., on "The Relative Ages of Igneous Rocks," by S. Allport, F. G. S., page 450.

† Prof. J. W. Judd's paper on "The Older Peridotites of Scotland" bears strong testimony in favor of Bischof's view, that hornblende is always a secondary mineral, as well as of the value of Bischof's caution that a mineral may be a secondary or derived one, although it may be "perfectly clear and fresh-looking," and may exhibit "no trace of its secondary origin." See Q. I. G. So., Vol. XII., No. 163, page 404.

Since writing the foregoing, we have perused with great interest Mr. J. J. Harris Teall's article on "Hornblende-bearing Rocks," published in the Geological Magazine for August, 1886. In this paper, while referring to the numerous cases in which "the hornblende is undoubtedly secondary; in others," he observes, "including the rocks now under consideration, it is certainly original." We would venture to suggest that from the point of view taken in the text, it becomes necessary to define exactly what we mean by an original mineral; for, following Bischof and others, we regard the typical minerals of any granite whatever, namely the quartz, orthoclase, and mica, to be in all cases *secondary minerals*, the result of hydro-thermal fusion on a totally different rock. If, however, it is admissible to term the typical minerals of granite thus formed original minerals, then, in that sense, certain hornblendes may be original, but not otherwise, for the weight of evidence tends clearly to suggest the probability at least that, as Bischof concluded, hornblende is invariably the product of some kind of metamorphism, and more recent experiments show that it cannot be produced by pure igneous fusion.

often arbitrary. Thus we readily perceive the steps by which, as Kinahan has observed, the whinstones (dolerites, metaphyres and diabases) are, or may be, eventually altered to granite.*

When we come to speak of the dolerite dykes and lavas of the Hawaiian group we shall endeavor to show that a separation of the more feldspathic from the ultra basic lavas may often commence from the simple subsidence in a molten dyke of the olivine by its weight and infusibility, and which leaves a dolerite which appears very suitable for conversion to a diorite.

If quartz, orthoclase, mica, talc, serpentine and hornblende are secondary minerals or transmutation products from olivine, augite and labrador, or anorthite, we have only remaining the other more silicated plagioclase feldspars to deal with amongst the main rock-forming minerals, and which may be the result of transmutation. The different varieties of augites and hornblendes, would be also transmutation products. The large class of silicates of alumina, such as tourmalines, and audalusites, are admitted to be secondary minerals; as are also the garnets, epidote, calc and other spars, the zeolites, chlorite and the iron ores. All these minerals can be derived from the decomposition, reassortment and recrystallization of the elements of dolerite or basalt, and without the addition of any new ones, except such as may be derived from the atmosphere. Gypsum and some metallic ores, and a few minerals, receive however, a new element—sulphur—which seems neither to be derived from the dolerite, nor from the atmosphere. †

The plagioclase feldspars, labradorite, audesine, and oligoclase, have been considered by Tschermak, Sterry Hunt and others, to be mixtures or modifications of the

* Geological Magazine, Vol. VIII., 1871, page 266.

† See Appendix, on volcanic sulphur, sulphuretted hydrogen, nitrogen and carbonic acids.

two most distinct species of plagioclase, anorthite and albite; but Professor Heddle contends for the distinction of all these species, and especially of labradorite—as do also Messieurs Fouque and Levy.*

From the point of view now taken anorthite and labradorite would be the original feldspars, formed from fusion, whilst albite, unlike the other plagioclase feldspars can hardly be said to have been produced by pure igneous fusion,† but being the most highly silicated of the plagioclase feldspars, it is probably a secondary mineral, resulting from the gradual loss of lime by one of the more basic varieties, and the substitution of soda in lieu of other alkalies. It is also generally found associated with the older and more silicated rocks, thus taking its place in the system in company with quartz, orthoclase, and mica, as the more silicated and the derived minerals.

It may be observed here, that the feldspars can be arranged in a regular series from anorthite to albite and orthoclase, showing, like the augites and hornblendes, a general decrease of lime as the rocks with which the minerals are usually or characteristically associated, are older. Not necessarily, because the minerals in the older igneous rocks were originally different to those erupted to-day, but because it seems a necessity that when minerals and rocks are long exposed to atmospheric influences, they should lose lime and bases. Other things being equal, the older the rocks the more silicated, or less basic we my expect to find them,‡ whilst as a matter of fact, this is the testimony by nearly all geologists.

There is a remarkable apparent exception to this rule

* Synthese des Mineraux el des Roches, par F. Fouque et Michel Levy, Paris, 1882, p. 140.

† *Ibid*, pages 141, 14'. See Appendix, for extracts from this work, bearing on these questions.

‡ In the Manual of Geology, by Jukes and Geike, third edition, 1871, page 288—we read as follows:

"Another fact which a general survey of the character of our volcanic rocks soon brings before us, is, that as a who'e, those of earlier date differ distinctively in composition from those of more recent ori-

in certain large eruptive deposits in the Archæan formation, represented by norites, gabbros, etc., which are found in different parts of the world, belonging to this early period, and which are strongly basic. This seems to arise mainly from the large quantity of olivine which originally entered into their composition. They appear to have been olivine-dolerites, such as are erupted on Hawaii to-day, and which escaped a thorough metamorphism. Still they often appear strongly silicated and hydrated. These however, may have, in many instances, been broken up and re-assorted, forming clastic strata.* Dana says, however, that some of the Archæan formaations appear never to have been under water, † which may have something to do with these very old olivine, or basic rocks, retaining to-day, so much of their basic character.

Thus it seems that nearly all minerals and rocks may be arranged in a regular series, commencing with the cosmical and basic volcanic minerals, olivine, augite and

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gin. From the first traces of volcanic activity in this country, up to about the close of the Old Red Sandstone, or beginning of the Carboniferous series, the interbedded (that is, contemporaneous) igneous rocks, consist, for the most part, of highly felspathic masses, to which the names of chinkstone, claystone, compact felspar, porphyry, felstone porphyrite, too, have been given. In most of these rocks there is an excess of silica, (55 to 80 per cent) which is sometimes found separated out into distinct granules. On the other hand, from the upper part of the Old Red Sandstone, or the lower numbers of the Carboniferous series, up to the end of the long history, the erupted masses, are chiefly augitic, as basalts and dolerites, (including melaphyres and diabases). In these rocks free silica is not a normal constituent, while the alkalies, alkaline earths and metallic oxides, form on an average about half of the whole mass. In the former class the acid element predominates, in the latter the bases are specially conspicuous."

* John E. Marr, Dawson, and many other geologists, have often called attention to the circumstance that large masses of the Archæan rocks may be pyro-clastic strata, we would suggest, formed on land, and in the sea, in great volcanic archipelagoes.

† Manual of Geology, edition of 1880, page 150. "The region (Archæan in North America) appears to have been, for the most part, out of water ever since the Archæan era." Whatever is true in this respect, of one great formation in one part of the earth, is probably true of the same formation in other parts of the earth, for as elsewhere pointed out, the tetrahedroid has collapsed and vibrated as a unit.

labradorite, (or anorthite,) and that as the rocks, (with certain exceptions however,) are shown to be older, so the minerals in them appear to change into others with less lime and more silica. In a large number of cases, the changes are clearly made out, whilst the changes from augite to hornblende on a great scale have recently, as we have seen, become well established. The more or less gradual silicification of all rocks, in the course of ages, by deposits of the very stable mineral, pure quartz, is beyond dispute. Even organic matter of all kinds, and of all ages, has been constantly silicified, and appears to-day as pure silex. The older the rocks then, the more silicious we may expect to find them. We must not forget also, the important effects of the constant chemical combination of minerals with water during all geological time, and which at the same time indicates its constant action. The final result is a series of siliceous and hydrated rocks—distinct results, due to one agency—in which the lime and iron mainly, have either disappeared entirely, or they are found partially segregated in separate strata. In this general progress from basic to acid and hydrated minerals, there are several distinct affirmations, which are true regarding them, speaking at least in a broad sense. The minerals—as they are evolved in time, and therefore the rocks of which they are composed—become less subject to the action of acids, or to atmospheric influences.* They become less fusible, (better able to resist the heat to which they are subjected to below, without fusing.) They become of less specific gravity—so that the continents which are mainly formed of them float well up on the general substratum. In fine, they become conti-

* Bischof says: "As mica is to such a slight extent liable to alteration by atmospheric agents, it might be inferred that it has been formed under their influence, and is the result of their constant reaction upon a great number of minerals, which furnish the material for its formation." Chemical Geology, vol. II, page 366. This principle may well be applied to other minerals.

nental minerals and rocks, and were it not for the constant injection and outpour from the universal basic substratum, with fresh supplies of less firmly combined, or more easily decomposed and basic elements, organized life on the earth which so much depends on them, would suffer materially. Granite and its minerals, as well as kaolin, hydrous mica, gypsum, serpentine, limestone and dolomite, are the rocks and minerals which foreshadow the end of all organized existence on the earth, and the locking up of the whole atmosphere and ocean in the solid rocks, as astronomers and chemists tell us, is now probably the case with the moon. Thus whilst the ocean changes the rocks—the rocks absorb the ocean. Or—the recognized gradual absorption of the ocean—means, a gradual modification of the minerals which compose the rocks of the earth's crust.

But the question will occur—where have the segregated basic elements gone? Have they too, not been buried, although separate, with the more silicated sediments, and should they not again appear, after re-melting, as basic plutonic rocks and lavas, as Dr. Sterry Hunt contends? Or rather, why, on this theory of granite and the more silicated rocks, should not the average of the lowest strata of the earth's solid crust that we are acquainted with, exhibit a fair specimen of the elements of the rocks above it, notwithstanding that they may be segregated, in acid and in basic strata?

But the upper strata, as Jukes, Geike, Dana and other authorities tell us, are more basi cthan acid, whilst it is certain that the lower and generally older continental strata, are more acid than basic.

To obtain an answer to this question we have to ask another. Have the continents always been continents? and the oceans—oceans? If they have, as all recent discussion tends to show, then both continents and granite rocks may be no more than local phenomena. It is cer-

tain that nearly three-fourths of the earth's crust on oceanic areas does not show any indication of either.

This relative permanence of the continental or upheaved, and the oceanic or depressed portions of the earth's crust is such a fundamental question in all geogenetic enquiry that it may be well to ascertain the most recent views of geologists regarding it.

It is well known that Professor Dana has long upheld this view. It has been confirmed by Wallace, on biological grounds, as well as by Professor Milne. W. B. Carpenter and others. Professor Geike in his Text Book of Geology, 1882, sums up his remarks on the entombment of organic remains thus:

"It follows from these conclusions that representatives of the abysmal deposits of the central oceans are not likely to be met with among the geological formations of past times. Thanks to the great work done by the "Challenger" Expedition, we know what are the leading characters of the accumulations now forming on the deeper parts of the ocean floor. They have absolutely no analogy among the formations of the earth's crust. They differ indeed, so entirely from any formation which geologists have considered to be of deep water origin as to indicate that, from early geological times the present great areas of land and sea, have remained, on the whole, where they are, and that the land consists mainly of strata formed at successive epochs of terrestrial debris laid down in the surrounding shallow sea." *

It seems hardly necessary to observe that the whole theory of the tetrahedral collapse is in accordance with the general permanence of the oceanic and continental areas.

But Professor Geike goes a little further, and still, in accordance with the theory of the collapse of the

* Page 608.

earth's crust on a geometrical basis, and favors the view that upheaval and continents are local phenomena the result of the subsidence of the ocean beds. He says:

"It is evident that in the results of terrestrial contraction on the surface of the whole planet, subsidence must always have been in excess of upheaval, that in fact upheaval has only occurred locally over areas where portions of the crust have been ridged up by the enormous tangential thrust of adjacent subsiding regions. The tracts which have thus been, as it were, squeezed out, under the strain of contraction have been weaker parts of the crust and had usually been made use of again and again during geological time. They form the terrestrial regions on the earth's surface."*

Again he says: "Nor is there any sign that corrugation takes place beneath the great oceanic areas of subsidence." †

Professor Geike shows also the constant relation of corrugation and crumpling of rocks with the crystalline schistose structure, then, the relation between that and gneiss, and then that:

"There is no essential distinction between gneiss and granite save the foliated structure of the one and the amorphous structure of the other. But gneiss in a plastic state and squeezed into fissures, or between beds of firmer consistence, would doubtless consolidate as granite."

"Thus," he continues, "the study of metamorphism and metamorphic rocks leads us from unaltered stratified deposits at the one end, into true eruptive masses at the other. We are presented with a cycle of change wherein the same particles of mineral matter pass from igneous rocks into sedimentary deposits, then by increasing stages of alteration back into crystalline amorphous

* Ibid Page 912.

† Ibid Page 54.

masses like the original rocks, whence after being reduced to detritus, and re-deposited in sedimentary formations, they may be once more launched on a similar series of transformations." *

One of the principal changes however, which would take place during these processes, and transformations, would be the continual loss of lime and bases which basic rocks suffer while being subjected to them. But as the lime is mostly carried away in solution as carbonate of lime, it would not necessarily be all or mainly deposited with the detritus in the ocean on the flanks of the continental areas, to be again raised up by tangential pressure, but would be carried by diffusion over the other three-fourths of the earth's crust or over the ocean, and there be appropriated by organized creatures and deposited about shoals and volcanic islands as coral reefs, and in the ocean beds as globigerina ooze. Some compounds of iron and other bases might go with it.

And there in the great ocean beds these bases would remain, if continental and oceanic areas have remained relatively permanent, and we see a reason why granite and the lower strata of the earth's continental crust should appear with less lime and bases than the mass of the strata above them, which has been more recently supplied by outpours of the general basic substratum, and which has been for a shorter time under atmospheric influences.

Thus granite should, perhaps, go with the continents as a local phenomenon, when contemplating the whole sphere. No particle of it has ever been found on the islands of the central oceans or in the ocean beds. Neither have corrugations. But continents, corrugation, granite and gneiss have intimately binding relations with each other, so that the non-appearance of all of them over the deep central ocean beds becomes strong

* Ibid Page 308.

circumstantial evidence that none of them have ever existed there;* and especially when confirmed by the fact that continental animals and plants, and their fossil remains, are also absent from oceanic islands.

These mineralological considerations in connection with the hypothesis of a thin crust geometrically collapsing upon a universal molten basic substratum, thus help to explain, in a general way, why the lower continental strata should mainly consist of acid or silicated rocks; why the oceanic islands should be exclusively basaltic, and why continental or insular-continental volcanoes should be often rhyolitic or trachytic, or alternately trachytic and basic, or sometimes trachy-doleritic, and also why continental strata throughout, especially the more recent formations, should still be so largely basic; and above all, why the dykes which rise everywhere through granite and all other strata, should be commonly doleritic—whenever the locally formed masses of "granite rechauffe," or of the results of either long-continued aqueo-igneous fusion, or of clastic strata long subject to atmospheric influence, which have been re-fused or re-crystallized, become either solid or exhausted.

As already observed, the same causes which make the continental crust more siliceous or less basic, reduce at the same time its density or specific gravity. The Rev. O. Fisher, in his recent work, "Physics of the Earth's Crust,"† arrives at the conclusion from independent data that the earth's thin crust, under the ocean, is of a higher specific gravity than the continental crust, in the proportion of say 3· for the former to 2·68 for the latter. This is closely the relation which syenite (Sp. G. 2·70), as perhaps fairly representing the average density of the continental crust, bears to basalt (Sp. G. 3·) the

* See also Appendix.

† Page 205.

rock of oceanic islands; and supposing both to be resting on a molten substratum, this alone would account for a difference of about 2¼ miles in the height of the average continental surfaces over the oceanic sea bottoms, if the crust of the latter be about 20 miles thick, and of the former about 22½ miles; although the Rev. O. Fisher considers the continental crusts to be somewhat thicker than this, say 25 miles.

It has to be remembered also that in addition to the loss of lime and bases, the continental crusts become, as already observed, hydrated and oxydated to a large extent, which tends to reduce the density of the whole. Serpentine, gypsum, kaolin, and the long list of metamorphosed and hydrated minerals with their low specific gravity, must have an important effect in reducing the density of the continental crust.*

It might be supposed that the crust composing the deep sea bottoms would also become metamorphosed and hydrated, but without corrugation and fractures, the evidence is rather to the contrary, and it may readily be conceived that in an undisturbed sea bottom the water might penetrate a certain distance, and by its action produce a water-tight stratum which would prevent further influence. Even under an undisturbed thin stratum, as in the English Channel, and in many mines under the sea the ocean waters are found to be often absent, and to have produced little effect on the rock. Should deep fractures occur in the depressed ocean beds, these would tend to open from below, and to be rapidly filled by the molten basic magma into

* It has been said that crystallization increases the density of a rock. This is indisputably true with reference to crystallization from the slow cooling of a molten glassy magma, but it is equally certain that crystallization, accompanied by hydration and oxydation, etc. (metamorphism), reduces the density of a rock. The rocks in the earth's continental crust, which are crystalline, from cooling from fusion, are very few compared with those which have crystallized from metamorphic action.

which they were being depressed. But even if metamorphism should take place in the crust of the ocean beds, there would be no opportunity presented for the removal of the heavier bases, such as occurs on the raised continental areas. There is another circumstance to be borne in mind in considering the possible metamorphism of the rocks of the ocean beds, that except on the edges of the continental areas, there would be no possibility of the rocks being permeated by anything but sea water, the effect of which would be probably different to those of fresh water charged with carbonic acid, air and other gases.

The Rev. O. Fisher alludes specially to the same action going on, to which both M. de Lapparent and Professor Geike call attention, namely that continental areas seem to be connected with lines of weakness in the earth's crust, or at any rate, that they are the areas where the tangential compression due to the subsiding ocean beds has developed great fractures, but he supplements these authors by observing that the same process which makes continents, tends—as we here endeavor to show—to make granite and the less basic and lighter continental strata.

The terms in which the Rev. O. Fisher describes this action seem so appropriate to the case which is here presented, that we transcribe them in full:

"If such be the case," he says, "the tendency would be for the compression to take place in the direction from the shore margin towards the mountain ranges. The latter being continually denuded down, and the material carried to the shore margin again, and there accumulating, sinking and being again pressed toward the ranges, would cause a kind of circulation of rock from the coast line inland, and back again by way of the surface. Since by this means every part would in its turn be

subjected to atmospheric action, the more soluble basic constituents would be carried out to sea, and it is possible that it may be to this cause that the lesser density of the continental crust may be owing, even although the continental rocks have these constituents continually replaced by the intrusions of the magma below." *

It seems then to be a fairly reasonable conclusion that not only many of the granites, gneisses and schists, and the volcanic rhyolites and trachytes, but also the more basic—but still silicated—syenites and diorites, as well as the volcanic audesites and trachy-dolerites, most of which are found more especially on continental areas and continental islands, may be the product of volcanic dolerites or basalts transmuted and more or less deprived of their bases, or rendered more silicated by the action mainly of water and the atmosphere—mechanical and chemical—through long periods of time, and often after being more or less subjected to heat, water, pressure and contortion, under the weight of accumulated sediments,† although this is not necessary

* Physics of the Earth's Crust by the Rev. Osmond Fisher, Page 205.

† It has been universally noticed by geologists that metamorphosed rocks are generally crumpled rocks, and it has therefore, often been suggested, that the heat resulting from the compression and movement, may have been the main, or at least, an important factor in their metamorphism. On the other hand, it may be well worthy of consideration, whether one of the main conditions in the metamorphism of underlying rocks—that is, softening by the water that dissolves and transmutes them—may not be sufficient to account for the constant co-existence of crumpling and metamorphism, for we may assume that all the older rocks have been at one time or other subject to tangential strains, and by which the softer rocks would suffer most. Besides the very fact of metamorphism by water, involves also the idea of the expansion of the stratum. These circumstances may then, account for one stratum being found crumpled and metamophosed, above or below another which exhibits neither effect. M. Daubree has shown that the heat required for most forms of metamorphic action is not above that usually found at the surface of the earth in inter-tropical regions, or in extra-tropical regions during the older geological epochs; or anywhere, at a comparatively small distance beneath the surface. Water alone, which may happen from one cause or another, to penetrate and soak a certain stratum, may account, at the same time, for its being crumpled, both by softening it, and rendering it easily affected by the tangential pressure, as well as by expanding the whole stratum by metamorphism, whilst being confined

for effecting the first stages of the alteration to a less basic character.

These acid or silicated rocks appear to be, like the continents themselves, the results of the great land-forming process, which has been going on from the earliest period over nearly the present continental areas. Thus, as M. Daubree has suggested, "to the waters of the ocean may be due the granitic rocks of our planet," and in which term should, perhaps, be included the acid lavas as well as the syenites, diorites, and other hornblendic rocks, which are generally ranked as intermediate between the acid and the basic, or between the granitic and doleritic classes.

Volcanic matter then, from this point of view, would be the upper layer of the anhydrous basic molten nucleus or substratum of the earth composed of cosmical minerals and metals, but constantly found more or less modified and transmuted by water, steam, atmospheric and mechanical agencies; and chiefly by the separation and segregation of lime and the more basic elements, which become deposited mainly in the coral reefs and in the ooze of the great permanent oceanic depressions.*

by the pressure of the overlying rocks. We must not, however, overlook the effect of tangential pressure and movement—however arising—in producing certain effects in metamorphic action, particularly in the formation of mica—which Jukes called a form of mineral, rather than a mineral, that is, a mechanical rather than a chemical result. Capt. C. E. Dutton, (Penn. Mag., June, 1876,) has called attention to the importance of considering the metamorphism of minerals in the expansion and crumpling of rocks.

* A paper read before the Royal Society of Edinburg, by John Murray and A. Renard, on deep sea deposits, (see *Nature*, June 5th, 1884,) presents the following conclusions:

First. That they are "a new confirmation of the opinion of the permanence of continental areas."

Second. That the red clay found everywhere in the deep central ocean beds, "may be said to be the product of the decomposition of the *basic rocks*, represented by volcanic glasses, such as hyomelane and tachylite."

Third. That quartz and the acid rocks, lavas, minerals and sands, may be said to be "*absent*" from the central oceanic areas, and that the red clay is probably merely masked in the shallower central portions by vast organic deposits of carbonate of lime.

CHAPTER V.

ON THE NATURE AND CAUSES OF VOLCANIC ACTION.

"L'action volcanique dans l'acception propre de ce mot, ne saurait donc etre la cause premiere des grandes phenomenes qui nous occupent; mais les eruptions volcaniques paraissent avoir elles-memes des rapports avec la haute temperature que presentent encore anjourd 'hui les parties interieures du globe, et les analogies qui, au premiere apercu, nous feraient chercher dans l'action volcanique proprement dites, la cause des revolutions de la surface du globe, doivent nous conduire finalement a chercher cette meme cause dans le phenomene beaucoup plus large de la haute temperature interieure de la terre."—ELIE DE BEAUMONT. *

Thus far the consideration of the figure of the earth, the analysis of the earth's surface features, the distribution of volcanoes, and the nature of volcanic matter, has led directly to the hypothesis of a thin crust resting on a universal molten and basic substratum.

It remains however, to consider what may be the probable conditions, under which this liquid substratum constantly overflows the surface of the earth, not only at low altitudes, but at the tops of high mountains. Those who consider that all volcanic action is the result of either originally combined, or subsequently acquired water, would appeal to the resulting steam as the power which might in some manner, raise the liquid lava the comparatively short distance, which on the hypothesis of a thin floating crust, would intervene, between its natural surface level—in a fissure—and the highest part of the crust resting upon it, wherever such fissure might occur.

But the consideration of the volcanic phenomena ex-

* Notice sur les Systemes des Montagnes, Paris, 1852, vol. III, p. 1227.

hibited in the the Hawaiian Islands—amongst the most extensive and typical of the grander forms of volcanic action in both the past and the present history of the earth—has led us to the conclusion, that water and steam are not usually present in these lavas, and that if they were, it would not account for their standing for months and years from 3,000 to 13,000 feet above the sea level. Whatever power therefore, keeps the molten lava standing or spouting, on Hawaii, at these great heights, is probably the fundamental motive power which raises the lava in all volcanoes, but supplemented, disguised and complicated in many of them, with the effects of local water, which columns of molten rock rising through the earth's crust might very probably encounter, especially in dislocated areas.

Starting then, with the hypothesis of a thin crust, say twenty miles thick, resting on a molten substratum, the first question to ask is: how deep down should we probably find the surface level of the molten matter in a fissure connecting with it? How deeply immersed does the crust rest or float? In other words, what is the relation of the density of the molten and solid rock?

All observation and experiment seems to indicate, in the language of Sir William Thomson, "that whatever may be said about substances expanding at the moment of solidifying, cold solid rock is probably of greater density than hot molten rock." *

If this be a fact, and it is one that could be easily disproved, if it be not true, then there should be no difficulty if we observe that the molten substratum tends to rise above the surface of its own comparatively *cold* solid crust. If there were a tube prepared for it, in which to rise, the molten substratum—as long as it kept its heat —would rise above the surface of the cooled crust, in

* Address at the Glasgow Meeting of the British Association, 1876.

proportion as its mean density when it expands and rises in a fissure, is less than the mean density of the crust resting upon it.

But Sir William Thomson, has in the same paper, given it as his opinion, that this would be an unstable condition of affairs, and that the crust of the earth, if of greater density than the liquid substratum, could not remain on the surface, but would sink into the liquid like a rammed ironclad. *

It would seem however, that this analogy will hardly hold. † Masses of the crust of the earth, even when separated by fractures, need not necessarily sink far into a liquid of which the density increases rapidly with the depth. Our ironclad is assumed to draw, to use a nautical term, at least twenty miles of the liquid on which it rests, and by sinking slightly deeper, the mean density of the liquid may then be sufficient to prevent any further sinking.

We have to remember also, that a fractured segment of the crust of the earth is situated very much as the voussoirs of an arch are placed, and the molten substratum, can only rise with some difficulty, through the eighteen to twenty-five miles of the fissures between them, and which the weight of the segments has a constant tendency to close. As long as the fissures are kept tight all round the earth, it is evident that the crust could not sink at all, but would be borne up by the internal liquid, as a tight piston is borne up in a cylinder with any liquid beneath it, whatever the relative densities of the two. ‡

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* *Ibid*, page 346.

† For some practical remarks in reply to Sir William Thomson's views quoted above, see a communication in *Nature*, November 2d, 1876, page 5. on "The Solidity of the Earth," by W. Mathieu Williams.

‡ It is not unusual for writers on geological subjects, who do not see their way to admit a thin crust of the earth, to draw a circle on the page to show how extremely insignificant is the proportion between

But we know that fractures do exist in the earth's crust which do not seem to be tight, and it is part of the present hypothesis, that the molten substratum, being of less density than the cooled crust, rises in those fractures by the hydrostatic pressure and runs over the surface. Whatever expansion may be due to the relief of pressure in the risen column, increases its height, and enables it to overflow at a greater altitude.

But there is another well known quality which belongs to the liquid substratum, if we assume it to be composed of ordinary lava, which is not always possessed by the water in which the rammed ironclad sinks, and which further destroys the analogy; namely, that when it is exposed at the surface of the earth, and even when it rises in fissures of the cooled crust, it solidifies or freezes very rapidly, and as it can only escape by narrow fissures, it hardens into stone; and as one flow runs over the other it builds a tube on the surface of the earth, up which the liquid substratum rises, until the increased height of the column balances the weight of the segment of crust. All becomes then in equilibrium. The columns of the interior liquid substratum, rising above the earth's surface in the cones, become the substitute for a tight piston.

It may assist in more easily conceiving this condition of affairs, to consider the case of a piston in an upright cylinder, supported in water. As long as the piston re-

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the earth's diameter and a crust, of say twenty-five miles thick, and which appears, when shown in due proportion, as a thin line, and respecting which it would be difficult to predicate anything in a mechanical point of view. This, however, is merely appealing to a scale which is not appreciable by our limited powers of perception, and taking what advantage they may of their deficiency. If the half section of the earth were drawn on the curtain or screen of a theatre or lecture hall, showing it fifty feet in diameter, (quite a convenient size) a crust of twenty miles deep only would show one and one-half inches thick. If this were colored red on a white ground, it would exhibit itself as a very important crust, especially if the spectators bore in mind that what they were looking at did not represent simply a ring or hoop, but the half section of a complete spherical solid envelope.

mains water-tight, it will be kept on the surface of the water, whatever its weight may be. If a hole now be bored through the piston from the surface to the under side, it will sink, and the piston will descend, (neglecting the friction of the sides) not as in ordinary floatation, until it has displaced its weight of water; but merely until the water has risen in the hole (whether a large or small one) to a height such that the weight of water in the column shall, when multiplied by the number of times that the area of the opening is contained in the area of the piston, just balance its weight. If the piston be heavier, or more dense than water, the water will rise through the hole and the piston will sink to the bottom of the cylinder. But now, if a tube the size of the opening be fastened water-tight in the hole, and projecting above the piston, and this be again allowed to descend, the water would only rise in the tube until the head of water again balanced the weight of the piston, and the whole would float, or more correctly be sustained.

Thus the molten lava in the volcanic conduits connecting with the molten interior of the earth, and usually found built up far above the earth's mean surface, forms a head of liquid which supports the earth's crust, on the well known principle of what has been called the hydrostatic paradox, but which, the qualities of the liquid being given, is really no paradox.

The principle is the familiar one, often used as an illustration in text books, of the hydrostatic bellows, the only difference being in the case of the earth's crust, that the top of the bellows on which the weights are supported is leaking, whilst the liquid which escapes either freezes and closes the leaks, or builds up frozen pipes or cones, in which the liquid rises again to the proper balancing height.

A practical illustration of the principle may be seen

where the ice over a pool in a severe frost, has a large number of skaters upon it, making the total weight of the ice (with the skaters) greater than the weight of the same bulk of water. In this case when a crack occurs, the water may appear above the level of the surface of the ice, but in a very severe frost there is little danger, as the crack rapidly freezes together, whilst the outflowing surface water also freezes and thickens the ice. A more exact comparison would be if a sheet of ice were regularly loaded all over with stones frozen into it, so that the specific gravity of the crust would be greater than that of water. In a very intense frost, although the water would rise through a crack formed in the ice, it would freeze as fast as it appeared, and the weighted ice would not sink.

The crust of the earth may be looked upon as a weighted ice crust in a constant intense frost, but a crust that is continuous with no bounding edge. The moment a rising column of lava runs over the surface, it becomes exposed to radiation and withdrawn from the heating effects of convection, and there is a rapid tendency to solidify, thus forming stone tubes or cones and conduits in which the lava column may continue to rise. *

It is evident that in this hypothesis of the earth's crust being supported by high liquid columns of less density

* Since writing the above, we have been furnished with an illustration of such an effect in ice, by a short communication which appeared in *Nature* of April 10th, 1884, from A. P. Colman, Faraday Hall, Victoria University, Coburg, Canada, which we transcribe in full:

"ICE VOLCANOES.—The past winter has been unusually cold and stormy in Ontario, and, as a result, an uneven strip of ice 100 to 200 yards wide, has accumulated along the lake shore, sometimes forming mounds twenty or thirty feet high. Many of these mounds are conical, and have a crater-like opening communicating with the water. In stormy weather every wave hurls a column of spray and ice-fragments through the opening. The ejecta freeze as fast as they fall and add to the height of the cone. In high winds the coast seems fringed with miniature volcanoes in active eruption. After a time the crater becomes clogged with ice, and the volcano may be looked on as extinct. Often a second crater is formed just to seaward of the first, and growing upon its ruins."

than the crust, we have to consider that the added weight of the cones, built up by the congealing liquid, has also to be supported. It is equally evident however, that from their conical shape, they do not add to the weight to be supported, in the same proportion that the liquid columns rise in height, that is to say, the balancing power of the rising column of molten lava must be constantly gaining on the weight added to the crust by the cones. On considering the hydrostatic conditions here assumed to exist, we have to remember also, that the area covered by a volcanic cone, or by several cones, is not an absolutely independent area, as far as its liability to sink from added weight is concerned, but may be partly sustained by the resistance to a vertical shearing strain along the fissures which may separate it from the neighboring areas, and on which there may be no added weight, and which fissures may be soldered together by congealed lava. In this case the added weight of the cone may merely produce a general deflection of the crust over a considerable area, and without producing a rupture. It might easily occur however, that the added weight becomes sufficient to shear the crust and partially sink the segment on which the cone is built, and both cases seem to occur in nature in regions where great volcanic piles are formed. But now other circumstances prevent an indefinite amount of either the bending or sinking of such an area, for by the hypothesis the density increases rapidly with the depth. It is readily seen that a comparatively small vertical sinking of the earth's crust under a volcanic cone would again support the weight of the cone, both because the mass immersed in the liquid per foot of vertical sinking, is so much greater than the conical mass to be supported, per foot of vertical height, and because the density of the liquid substratum most probably increases rapidly as the segment descends.

When we remember, therefore, the increasing density with the depth of the liquid, and the tendency of the fissures to freeze, or solder together, there seems no difficulty in conceiving how the extra weight of the volcanic cones is supported. At the points of intersection of two fissures where they may not close or freeze, the result is shown in the further up-building of the cone, notwithstanding that this may produce a further, but comparatively minute amount of subsidence.

We shall present some considerations in the next chapter, on the volcanoes of the Hawaiian group, which indicate how complicated the conditions of subsidence and upheaval in volcanic areas may become, both sometimes going on at the same time. Thus an island, or a large portion of a volcanic cone may be raised up by local upheaval at faults, whilst the general crust on which it stands may be gradually subsiding. We shall further show the probability that the Hawaiian volcanic chain of extinct craters have subsided to the northwestward in increasing ratio from a stationary axis about Hawaii, which island appears to have long remained at one general level, except at the active end, which has suffered, and is now continually experiencing, local subsidences and local upheavals.

The Rev. O. Fisher, in his enquiry into the "Physics of the Earth's Crust," has also arrived at the conclusion —on independent grounds—that the crust of the earth must be thin—about twenty to twenty-five miles thick —and be resting on a liquid substratum. This liquid he endows with a property of less density, and of ability to overflow the surface of the crust, in consequence of its aboriginal combination with water, which expands into steam on being relieved of the pressure of the crust, as it rises into openings anyhow formed in that crust. This is equivalent to assuming that the liquid molten substratum, when allowed to occupy an opening, or fissure in

the floating crust, becomes of less mean density than the crust, which according to the view here presented, is just the actual relative condition of the crust and substratum, without the necessity of appealing to a hypothetical combination with water. *

This potential relative lightness, or small specific gravity, is precisely the quality we may assume for the hot molten rock in its ordinary condition, when allowed to expand into, and to rise in a fissure or opening in the cooled crust resting upon it. We do not require the combined or compressed water to reduce the relative specific gravity of a column of the liquid substratum, even if we saw it there, but in some of the largest volcanoes on the earth, we do not see it. The relief of the pressure of twenty miles of rock on hot molten lava—without water—would allow it to expand just the amount that we may assume it to be compressed at that depth. When the column has risen in the fissure by hydrostatic pressure as well as by expansion, to the balancing height, the compression and resulting density *below* is renewed, but the average density of the risen molten column must be less, from the lessened pressure above, than the average density of the substratum twenty miles beneath the crust, or beneath the molten column. The principle of expansion must be assumed to be at work in these columns of molten rock rising in fissures, without calling in the aid of water and steam.

Not endowing the molten lava with adventitious qualities which it may not possess; but only with those which all physicists will admit, in all probability, belong to it, we see that with a denser † thin crust resting on

* It seems probable, as many physicists have surmised, that whatever water may have been at first, or in the earlier periods, occluded in the molten nucleus, must have escaped in steam long since, perhaps when, or before it first began to crust over.

† That is, more dense than the average density of the column in the fissure, although it may not be more dense than the liquid substratum at its base. We have to remember that on any probable hypothesis

it, it may still rise above the surface to any height compatible with the probable mean difference of density between the two—the density of the lava column becoming less as it rises—and when it has risen in the frozen tubes formed by its own overflow, to a height which hydrostatically balances the weight of the crust, it will stop.

We are now in a position to form an intelligible conception of the extreme delicacy with which large sections of the earth's crust seem to be balanced, and how, as many geologists are only just beginning to recognize, the deposition of sediment over the area of a Delta, or of ice and snow over a mountain region, will cause either to sink gradually with the added weight, whilst the removal of matter by denudation, or the melting of the glaciers, will cause the same regions to gradually rise. All geological history seems to form a chain of evidence in favor of the view that the earth's crust has been always thus on the balance.

We may also understand how many of the different agents which have been appealed to by geologists as having some connection with volcanic action have produced their effects; the transfer of large amounts of sediment or other matter from one area to another being one. But "changes in the incidence of pressure," from the varying tangential thrusts in the crust, arising from the greater

of the relative densities of the earth's thin crust and the molten substratum, from which we may assume it to have solidified, that even a *hot* solid crust of metals or slags, will usually float no lighter than about "flush" with the molten matter from which it solidifies. This is the case with iron and most metals, and seems to be probably the case with basalt, so that there is no necessity, in the oceanic regions at any rate, of looking about for a means of lifting the molten substratum in open fissures, to the level of the surface of the earth. Cooling and detrification of the crust, and the subsidence of the heavier, baser elements in the molten columns, all conspire to make the crust of the earth, over volcanic areas, more dense than the molten substratum in the fissures, and thus cause the liquid to rise gradually above the surface; to say nothing of the circumstance that the central oceanic crusts are probably also, the depressed areas in a general system of tangential thrusts.

relative contraction of the interior liquid, must have been an important and constantly acting force on the liquid columns and on the crust which they support, notwithstanding that the action might be slow and intermittent, and only exhibiting itself, as portions of the crust finally give way under the strain of compression; or, as the liquid columns happened to be affected by a further distortion of the spheroid, or by the return of the planet to a form nearer that figure, under the influence of rotation. *

The probable effect of the attraction of the sun and moon on the liquid nucleus, and on these columns, may be gathered from what has been brought forward in Chap. III, on the "Distribution of Volcanoes." That of the attraction of the larger planets also, cannot be disregarded in a volcanic system so delicately equilibrated.

In fine, when any of those events occur, which as Darwin expresses it, may cause a change in the configuration of the surface of the fluid nucleus, or as Beaumont still more directly defines it, causes a change in the height of the fluid columns; the molten lava in the conduits of neighboring volcanoes, already built up, far above the mean surface of the earth, is seen, as Darwin suggested, "to splash up like water in the ice of a frozen pool when a person stamps on the surface." †

* If we notice the action of confined water under pressure, it will readily be understood how extremely minute may be the change of figure in a large spherical container, to produce great effects in the level of the water in small pipes which may lead from it. How an insensible change in the earth's figure, may cause an appreciable change in the height of the molten columns in fissures in the crust.

† We sometimes find geologists objecting to the hypothesis of a fluid substratum of "surging lava," beneath a thin crust of the earth, on the ground of its general stability. May not a better case be made out in *favor* of a fluid substratum, on the ground of the general instability of the crust? Let us remember how quietly an exploring ship with all her crew, may remain on a crust of ice for years, and yet how suddenly she may be crushed to atoms. Our experience of molten stone, or lava, let alone—so to speak—is, that it is as quiet a substance as molten iron, molten ice, or cold water. All are liable to violent movements under changing external conditions.

Thus volcanic action presents itself as one of the phases of secular refrigeration, and volcanic cones appear as part of the self-acting machinery by which the cooled crust of the earth is sustained by liquid columns of the less dense upper layer of the molten nucleus, and the latter, kept within bounds in its overflow, * notwithstanding that its more rapid contraction is constantly causing the denser crust resting upon it to collapse, to crush and to fracture.

It is sometimes assumed, even by geologists, that the deep fissures in the earth's crust—speaking generally—are the result of volcanic action, or of the force exerted by, or through the molten matter which appears in them. Jukes and Geike have, however, called attention to the apparent independence of the fissures in the earth's crust and the molten matter which fills them. They say, "While instances do occur in which the dykes have filled very uneven fissures, the prevailing regularity of their thickness and direction tends to show that the igneous rock has not itself been the cause of the fissures. These have, much more probably, been due to the action of a general powerful agency, of which the extravasation of the igneous rock, is only itself additional evidence. There is reason to believe that in many, if not in most cases, the fissures existed before they came to be widened and filled with intrusive rock, so as to become dykes. This is especially the case where they have not been mere rents in the crust of the earth, but rents attended with the upheaval or depression of one

* It is not to be understood that these high columns of liquid lava are necessary to sustain the denser crust provided, there were no fissures in that crust. With a continuous, unbroken crust of greater density than the substratum, it would be sustained, as we have before said, just as a heavy iron piston would be sustained by any liquid in a vertical cylinder. The volcanic cones enclosing columns of the liquid prevent the indefinite flow of the substratum over the surface of the earth, even when the crust is fractured, and the sinking of the crust from this cause. Even a denser *viscous* crust may be sustained on this principle upon a less dense substratum, as Hopkins intimated.

or both of the sides—that is to say, faults. We find dykes coinciding with such lines of fault, but in such a way as to show that the faults are of older date, for the dykes are found also to cross the faults without being deflected thereby." *

Chap. III, on the "Distribution of Volcanoes," taken in connection with our general theory, not only confirms these views, but shows that the grand volcanic fissures of the earth's crust, are not the result of any elastic or other force inherent in the molten matter which injects them, but are the result of the collapse of the crust, and of the luni-solar tidal elongation of the earth's molten nucleus or substratum. Both these phenomena are, however, inseparably connected with volcanic action, in the broad sense, whilst all the facts and phenomena taken together, point in the clearest manner to a thin, easily ruptured crust of the earth, and a molten substratum beneath it, both acted upon by gravitation, internal and external, and by the earth's rotation.

The explosive action—the effect of steam and occluded water or gases—so common in many volcanoes, may merely mean, that water in some shape, accidentally gains access to the rising lava column.

If this be the true principle of volcanic action, then the different igneous phases which are observed as having occurred in all parts of the earth during the past geological epochs, are simply explained, without calling to our aid new hypotheses, for there may have occurred explosive action anywhere, or at any time, where the fissures already made, † became filled with the basic

* Manual of Geology, by Jukes and Geike, 1871, page 264.

† The late disastrous explosive eruption in New Zealand, (June 10th, 1886) appears to have been an unusually violent display of geyser action in a well marked geyser region, or, as Dr. Hector calls it in his preliminary report to the New Zealand Government, "a purely hydrothermal phenomenon, but on a gigantic scale." (See *Nature* Aug. 26th, 1886, page 393.) No emission of molten lava has been seen in connection with it, although there can be little doubt that it existed

molten substratum, or by the more acid sediments remelted by it, and which happened to encounter water in its rise. These fissures and their offshoots, exhibit themselves to-day as dykes, intercalated sheets, or laccolites of basaltic, dioritic or more acid rocks. But often the same fissures filled with the molten substance under the hydrostatic head of pressure, might overflow along their length, and deluge the surrounding country with vast floods of lava.* Or, the main fissures closing up, or sealing up with congealed lava, along their length, may have remained open at the intersection of two, where the passage would be enlarged by the melting of the corners, and the molten matter might continue to slowly rise in such openings, by the pressure or weight of the earth's crust—affected by collapse, rotation and other forces, as already pointed out—and to well over steadily for ages, forming vast basaltic mounds, with tubes or channels in the centre of them, such as those of the Hawaiian Islands; but with little or no appearance of truly explosive action from the vapor of water, except as an entirely subsidiary phenomenon; or, perhaps, in the expiring stage of each volcano, when rain water might lodge in an old crater; or, near the coast line, when the molten matter rises to the surface just below the sea level.

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at a short distance below the surface, whilst the water in the lakes of the district appear to have gained access to it through a newly disturbed fissure along one of "the great fault-lines that traverse the North and South islands," as Dr. Hector suggests in the same report. This accidental access of an unusual quantity of water however, to the molten, or highly heated rocks below, was not the means by which the heat was brought near to the surface, for that has been at a small depth for centuries, the remains probably, of a former extravasation of lava from a fissure along the same fault-line; and the geysers which have been so long in action in this region, were but a milder, though more permanent phase of the recent great eruptions of water, steam, mud, stones, sand and pumice.

* The larger portion of those surface floods which were probably extravasated in the earlier geological epochs, have in the course of ages been destroyed by atmospheric action, or metamorphosed, so that today geologists are not agreed as to when and how to recognize even those which may still exist. See Jukes and Geikes Manual, 1871, p. 265.

The supposed difficulty that the molten matter in two neighboring volcanoes assumed to be connected with each other, and under the same head of liquid pressure, should stand at different heights, will be referred to more fully in the next chapter, as well as the question of columns of molten lava of different kinds, being connected with one molten mass.

CHAPTER VI.

THE HAWAIIAN GROUP AND OCEANIC VOLCANIC ISLANDS.

"The group (the Hawaiian) is consequently the key to Polynesian geology. It combines all the features which are elsewhere widely scattered, and they are so exhibited in progressive stages as to afford mutual illustration. An island like Tahiti, so broken into peaks and ridges, may excite wonder and doubt. The Hawaiian group suggests the same difficult problem as Tahiti; but an intelligible solution is at the same time presented for our contemplation and study." *

SECTION 1.—*Importance of Oceanic Volcanic Islands in any general Volcanic Theory.*

If we may now be allowed to assume a thin crust of the earth, resting upon a universal molten basic substratum, the overflows of which on continental areas have, through the action of water and the atmosphere, become more or less modified by the loss of bases or by chemical union with water, so forming acid or silicated, and hydrated rocks, the oceanic basaltic islands, often with active volcanoes emitting basic or ultra-basic lavas, fall naturally into their place.

The assumed depression or subsidence of the earth's crust, over oceanic areas, into this basic substratum, of less density, requires nothing more to explain volcanic action there, wherever fissures in the crust may occur.

But whatever general theory of the earth may be accepted, here is a great phenomenon to be accounted for,

* **Geology of the U. S. Exploring Expedition, by J. D. Dana.**

namely, that every island over all the central portions of the deep oceans, that is not coral—and these are supposed to cover basaltic rocks—is volcanic and basaltic.

It is a phenomenon that cannot be other than of paramount importance in any theory of volcanic action. Every fact therefore, connected with a typical group of oceanic volcanic islands, such as the Hawaiian, has some bearing on the general subject, and as we shall see, nothing is more prominent than the simplicity of many of the phenomena, and the general application of certain fixed principles to all the central oceanic islands.

One of the first impressions that arises in considering a remote Pacific island or group, is its insignificance; and certainly, compared with the vastness of the ocean that surrounds it, it is so. But it may be as well to call attention to the mass of volcanic matter visible above the sea level, in the single island of Hawaii for instance, which would cover all England with a stratum of basalt two hundred and seventy-four feet deep. * Artesian wells however, have penetrated 1,000 to 1,500 feet below the sea level, both on Hawaii and Oahu, at which depths the usual olivine-basalt has been found to be the lowest stratum,

* The bulk of the island of Hawaii, above the sea level, has been roughly estimated by the Hawaiian Surveyor-General as containing at least, 2,600 cubic miles of lava rock, and taking the area of England at 50,000 square miles, this would give a depth of basalt of 274 feet over all that area. It has been estimated that over a cubic mile of basaltic lava has been poured out over eastern Hawaii during the last half century, and this consideration, in view of the known enormous emissions of molten lava and of heat, in all parts of the globe, show that the late Mr. Mallet's estimate of the total amount of volcanic energy since the Tertiary epoch, may be represented by four hundred volcanic cones of 6.54 cubic miles each, (see Trans. Royal Society, vol 163, pt. 1, p. 208) can be no approximation to the true probable amount of volcanic energy or heat lost, since the Tertiary period. The island of Hawaii alone, above the sea level, represents Mallet's total of four hundred volcanic cones, or 2,816 cubic miles of cooled lava, and this might have have been poured out from two active Hawaiian craters, at the known rate of ejection for half a century back, in 130,800 years, which would be considered by geologists as much too low an estimate for the duration of the Quarternary and recent epochs. But the loss of heat at the Kilauea lakes alone, by radiation and remelting during the last half century, must represent a greater total than that represented by all the lava streams from eastern Hawaii during the same period.

but nothing like either granite, gneiss, or the old sedimentary rocks, has been encountered.

Judging from the regular slope which is continued under the ocean on each side of the Hawaiian group, until the nearly level bottom of the ocean is reached, it seems probable that the whole is composed of a succession of lava streams, and that the mass of basalt above and below the ocean, covers a space of at least 400 miles long by 150 broad, representing a conical ridge two and a half miles deep at the apex, or equal to about 75,000 cubic miles of volcanic matter; enough to cover the whole of Europe with a stratum of basalt one hundred and seven feet thick.

But as Dana has remarked, the Hawaiian basaltic lavas probably continue under the coral for 2,000 miles instead of 400, the situation of the tops of the volcanic mountains being now only indicated by subsided lagoon islands, coral reefs, and shoals along the north-westerly trend of the group.

If this vast mass had been upheaved and exposed for ages to degradation, metamorphism, and to local changes of level, it would be difficult—perhaps impossible—to show the craters from which the lavas had issued, and would form a lava flood as large as, or perhaps larger than any of those over the earth which have been considered to proceed from fissure eruptions as distinguished from what is called ordinary volcanic action.

SECTION 2.—*The Main Rocks of the Hawaiian Group and of Oceanic Volcanic Islands.*

Prof. Dana, in "The Geology of the U. S. Exploring Expedition," has given a pretty full account of the rocks of the Hawaiian group, in which he makes them mainly basaltic, with a large proportion of chrysolite. He refers also to a rock, which he calls "clinkstone," of a light grey color, which he distinguishes from the olivine-basalts of thè group, and invests it with very consider-

able theoretical importance, as constantly composing the central axis of the mountains, which he calls feldspathic as contra-distinguished from the surrounding basalt.

As this distinction seems to be of much importance the following quotations from Dana are presented in full:

"*Rocks*—(speaking of the rocks of Oahu,) the material of the layers is mostly a black, or brownish-black basaltic lava, containing chrysolite. It is a heavy rock, more or less cellular, like much of the basaltic lava of Hawaii and Maui, and sometimes has the ropy surface of a recent eruption. * * * Excepting the chrysolite no crystals or grains of any kind are to be detected. This black variety passes also into greyish or bluish rocks of similar constitution, but *containing less iron.* They vary in compactness and in the proportion of chrysolite.

"These again graduate into a clinkstone like that of Hawaii. At a locality about three miles east of Honolulu, a variety of this rock has a light grey color, and is speckled with a white soda feldspar, which constitutes the greater part of the whole; but besides there are dark green points of impure augite. The rock is exceedingly compact, without a trace of a cellule, and it breaks into coarse plates or slabs, owing to a lamellar structure." *

Again, speaking of the rocks of the Pacific volcanic islands, he says: "The rocks of the mountains in the Pacific have been described as varying between basalt and clinkstone or porphyry, the former passing into the latter, as feldspar becomes the predominant and finally the constituting mineral. The basalts are either homogeneous and wholly uncrystalline, or they contain crystals of augite or feldspar, or grains of crysolite, or magnetic iron; again they are compact or vesicular; and the latter pass into scoriaceous and obsidian varieties.

* Geology of the U. S. Exploring Expedition, by J. D. Dana, p. 238.

The feldspathic rocks are mostly a clinkstone, or a compact rock like the base of porphyry, and approaching trachyte; and they pass into a variety of crystalline texture like syenite.* The feldspars as far as examined are soda feldspars. This is the case with the lavas of Kilauea, the glassy crystals of Maui, which are near audesine, and other crystals from Samoa.

"The most striking fact connected with these relations has been pointed out, (Dana, Ex. Ex., pp, 204, 269, 368,) as noticed in most volcanic regions, namely, the occurrence of feldspathic varieties at the centre of the mountains while the exterior and circumferential portions, consist of basaltic rocks; at the same time the former have usually a solid unstratified character. We refer to the preceding pages for the facts, merely instancing here, as regards the felsdpathic axis, the single case of Mauna Loa, on which there is clinkstone at the very summit, while around the slopes, wherever below the rocks are exposed in sections, and whenever recent eruptions take place, there is nothing but some variety of basalt or basaltic lava." †

The so-called clinkstone, which Professor Dana identifies at a locality about three miles east of Honolulu is unmistakable. The description is exact. It forms a large dyke over twenty feet thick, and the coarse plates or slabs are the result of a polygonal or sub-columnar structure running at right angles to the cooling surfaces, or across the dyke. This rock has a specific gravity of

* In a paper by Prof. Dana in the *American Journal of Science* for October, 1886, on a dissected volcanic mountain, (Tahiti) he observes, p. 254: "Up the Papeuoa Valley, six to eight miles from the coast, along the stream, I found many worn masses of a whitish granite-like dioryte," and in a note here he states: "The rock is called syenite in my report." A diorite is just the rock we should expect to find as the central bosses of old basic volcanic mountains, when dissected by denudation as Tahiti is. The augite becomes, as usual in older dykes, converted to hornblende, the absence of olivine being probably the result of its subsidence.

† *Ibid*, page 372.

about 2.90, and if composed, as Dana says, of a soda feldspar and augite, seems to be a true dolerite, and we presume, would not to-day be classed as a clinkstone, the only special claim which it can have to this term being applied to it, is that it has a metallic ring when struck with a hammer, but the specific gravity, and the fact that the minerals are soda feldspar and augite, seem to necessitate its being classed as a basic rock and a dolerite.

There can be no question that there exists a remarkable difference between the rock of some of these dykes (the so-called feldspathic clinkstone) and that of the lava streams which one might naturally suppose had proceeded from them. We have tried the specific gravity of a large number of the compact lavas of Oahu, and find it to be in the neighborhood of 3.07, whilst the "feldspathic" dykes have a specific gravity of 2.90 only. It is well known that the rapid cooling of a heavy basic lava materially reduces its specific gravity. The glassy edge of a small dyke, we have found to have the specific gravity of 2.68, whilst the rock of the same dyke towards the centre, will have a specific gravity of 2.80; and this specimen being from a narrow dyke, it has all probably cooled quickly, and shows a low specific gravity. Quick cooling however, cannot be brought forward as the cause of the comparatively low specific gravity of the so-called clinkstone of the Palolo Valley dyke, (three miles east of Honolulu, referred to by Dana.) On the contrary, this is a wide dyke, and it seems to have cooled slowly, as is evident by its not showing anything of glassy or tachylitic texture, but the feldspar and augite have had time to separate into minute points or crystals. This Palolo dyke is a vertical one, and has, according to the indications, remained in a molten state for some considerable time before cooling. We would suggest that this may be the simple cause of the difference in composition

between it and the lavas which have flowed over the surface. It is to be noted that there is not a particle of olivine to be seen in it, a mineral which is almost invariably visible in the surface flows. It is well known that olivine, being the least fusible mineral in molten basalt, solidifies first, and is constantly found, as shown by several indications, to exist as solid crystals in the molten lava, often however, with the sharp crystalline edges rounded off by attrition, or melting, or both. Olivine being at the same time a heavier mineral than a molten magma of feldspar and augite, would sink in it, under such circumstances as we have seen were probable in the Palolo dyke, that is to say, the molten magma was in large mass, was vertical, was cooling slowly, and not running over. The olivine would have an opportunity then to subside, and this and the slower cooling appear to be the sole difference between it and the surface flows; or rather perhaps, we might say, the slow cooling in mass, * has caused first, the solidification and subsidence of the olivine, and the incipient crystalization of the remaining labrador and augite. Some iron has probably subsided with the olivine. All the peculiarities of this rock may thus be accounted for, namely, no olivine, incipient crystalization of the remaining minerals, light color, lower specific gravity than that of the surface flows, and sub-columnar structure.

This does not seem to be an isolated instance, for Dana refers to a similar state of things on Mauna Loa, Haleakala, and western Oahu, as well as on other Pacific islands where so-called feldspathic and unstratified masses, are found instead of the more basic lavas, or olivine basalts, all round them. When the basic magma rises and overflows suddenly, without giving the olivine time

* Collateral evidence of the slow cooling, in mass, of this dyke is found in the regularity of its mineral composition. Many ships might be loaded with specimens almost exactly alike.

to chrystalize and subside, this mineral of course, shows itself in the surface flows as they cool, or it would be shown by analysis.

Darwin suggested, and Dr. A. Geike takes a similar view, that the separation of the acid and basic rocks may be largely due to a draining away of the heavier bases. The indications from the Palolo dyke and other feldspathic centres on the Hawaiian group, surrounded by more basic overflows, seem to be in accordance with Darwin's principle of action; for as has been remarked above, so long as the molten magma in the great dyke kept rising from the hotter regions below, and flowing over the surface, it might take its heavy basic constituents with it, in a molten state, but the moment the outflow was checked and the molten mass became quietly held in the fissure by hydrostatic pressure, the heavy basic and the less fusible minerals, olivine and magnetite would tend to solidify first, and sink, leaving the remaining mass more feldspathic.

We cannot help noting here Dana's remark regarding the rock of this Palolo dyke, and which any number of specimens would corroborate, that it "is exceedingly compact *without a trace of a cellule.*" Where are the evidences of the elastic vapors that are often theoretically assumed to raise this molten matter in the fissure? They are not there—which however, receives confirmation from the large dykes, lateral intrusions and laccolites all over the earth. It is true that some of the old dykes of the world may be supposed to have become compact or noncellular by subsequent infiltration and metamorphism, but there is no room for a suspicion of anything of the kind in the case of the Palolo dyke, as the minerals are pure igneous ones cooled from a state of fusion. *

But now comes in the effect of atmospheric agencies

* See Synthese des Mineraux et des Roches by F. Fouque and Michel Levy, Paris, 1882.

and water, acting through long periods of time, to still further differentiate these central feldspathic rocks, as well as the more basic outpours on the flanks, from the basic magma which gave them birth. Western Oahu is admitted on all hands to be more denuded and weather worn, and probably therefore, older than eastern Oahu. The same fact has been remarked of the western and eastern ends of most of the islands of the Hawaiian group. Dana observes of western Oahu as follows:

"The rocks of the western mountains are mostly a grey basalt or greystone, and are often somewhat cellular. They are frequently much porphyritic, small tabular feldspathic crystals being thickly disseminated. Some of the isolated ridges on the Waianae plains (see map) consist of a kind of clinkstone porphyry, allied to the clinkstone of Hawaii and Maui. The colors presented are various, as dull brownish-black, purplish, bluish-grey, and greyish-white; and the compact base is finely speckled in most parts with points of feldspar. On decomposition it becomes white, and so soft that it may be used like chalk." *

Dana further observes, speaking of a dissected volcanic mountain on western Oahu, that it shows trachyte at centre and basalt outside. †

But an analagous state of facts is noticeable between the eastern and western ends on Hawaii and Maui, as well as on Oahu. That is to say, the more recently erupted lavas show a distinctly basic or ultra-basic character, whilst the more weather-beaten, denuded and apparently older, western ends and the inner cores, show the lavas to be more feldspathic, first, as we would suggest, from the simple draining away of the olivine in the great central dykes and bosses; and secondly, from the gradual development, in the course of time, of small

* *Ibid*, page 250.

† *American Journal of Science*, 1873.

white crystals of feldspar, and the loss of lime, iron and other bases.* These western mountains of Hawaii, Maui and Oahu, have always given us the impression of having become grey with age, when compared with the more recently erupted volcanic mountains of the eastern ends. That the western mountains have been for ages longer exposed to atmospheric influences since the last lavas were erupted is palpable to the most casual observation. Their great central craters are almost obliterated, and stupendous, water-worn ravines separate the masses into isolated blocks, whilst the perfect volcanic domes of eastern Hawaii and eastern Maui, with their fresh and highly basic lavas, show what in all probability, the eastern mountains once were.

Captain C. E. Dutton, whose valuable papers connected with the United States Geological Survey are well known, has recently visited the Hawaiian group, and in a letter to J. D. Dana, dated Washington, D. C., Feb. 8th, 1883, refers to the character of the lavas of the four great mountains of the island of Hawaii as follows: He says:

"The lavas of both Kilauea and Mauna Loa seem to me to be of an abnormal type. The analyses are not yet made, and I can therefore, give only their superficial character. They have the appearance of being extremely basic, decidedly more so than normal basalts. I cannot help thinking that they may be fairly relegated to what Judd describes as ultra-basalts. Most of the lavas of Mauna Loa contain excessive quantities of olivine, many specimens being at least half composed of that mineral. The lavas of Kilauea, on the other hand, whether in the pit itself, or in the country round about, seldom show much olivine. But the eruption of 1840, which belongs physically to the Kilauea group, is highly

* Whenever a small, trickling stream runs constantly over our basic lavas, especially where there is much vegetation, the iron-rust can be seen deposited upon the bottom, as well as the oily scum on the surface, which is often seen when pig-iron has been lying in water.

olivinitic, while the last eruption of Mauna Loa shows little or no olivine. * I am led to suspect that the ultimate analyses of the two lavas, whether olivinitic or not, will show but little difference. In other words, I suspect that in some cases the olivine was crystalized in the lava before eruption, while in others it was not, the magma being very nearly identical in both cases.

"I spent a great deal of time in the study of Mauna Kea. This volcano contrasts strongly in its aspect with Mauna Loa. Its lavas are apparently more nearly normal basalts and show a somewhat wider range of variety." * * *

"I also visited Hualalai, which has an altitude of about 8,600 feet. It seems to be intermediate as regards the character of its lavas and many of its eruptions, between Mauna Kea and Mauna Loa; being more basic than the former, less so than the latter." * * *

"Kohala mountain, at the north end of the island, is about 5,400 feet in height, and its activity, no doubt, ceased at an ealier period than that of Mauna Kea. Its lavas are largely normal basalts, much of it approaching andesite in character. It appears to be notably less basic on the whole than the lavas of Mauna Kea." †

These observations fully confirm what we had noticed of the nature of the lava of these four mountains, although we had not been able to distinguish the slightly less basic character of the lavas of Hualalai than those of Mauna Loa. On the principle however, of a basic lava losing bases in the course of time, or as it is longer exposed to atmospheric influences—the effect is just what might be expected. Mauna Loa, the most easterly mountain, still covering its flanks with vast outpours of

* We would remark here, that the 1840 eruption broke out at a low elevation, whilst the last eruption on Mauna Loa proceeded from an orifice 8,000 to 11,000 feet above the sea.

† *American Journal of Science*, vol. 25, No. 147, March, 1883, C. E. Dutton, on Hawaiian Volcanoes, pp. 223, 224, 225.

ultra-basic lavas, no change is visible in them. Hualalai, the next volcano to the westward seems to be an expiring one, so that the lavas visible on its surface have probably been longer exposed, and show therefore, a somewhat less basic character. The next volcano, Mauna Kea, long extinct and much denuded—shows the lavas still less basic, they are "more nearly normal basalts." Kohala mountains, to the northwest, are so much denuded, or have been so long exposed to the atmosphere, that the volcanic configuration is nearly destroyed, whilst its lavas, in accordance, "approach andesite in character," and are "notably less basic on the whole than the lavas of Mauna Kea."

We have already seen that J. D. Dana has noticed the same combination in the character of the lavas of the eastern and western mountains of Oahu. The western, long exposed, worn down, and the lava feldspathic or "trachytic;" the eastern volcanoes more recently in action, having the lavas more basic.

Precisely the same thing occurs on Maui. The eastern, and almost perfect volcano, Haleakala, is covered with basic lavas, whatever more feldspathic kinds may exist at the summit. Dutton calls it "wholly basaltic and in its general characteristics a pretty close imitation of Mauna Loa." But this is what Captain Dutton says of the remains of the volcano of *West* Maui.

"The mountain piles which make up West Maui are much older. They are very much degraded by erosion, and literally sawed to pieces by gorges and ravines two thousand to three thousand feet in depth, with precipitous walls. Some of the scenery in these gorges possesses a beauty and grandeur seldom equaled. It is highly peculiar, and so far as I know has its counterpart only in other islands of the Pacific. I found here some lavas which appear to be true andesites, though in the main, the rocks are of a mildly basaltic type." *

* *Ibid*, page 225.

We have endeavored to show in Chap. IV. that basic rocks tend to become more acid or silicated, the longer they are exposed to atmospheric agencies, and here on the Hawaiian group are found a number of volcanoes which have all emitted lavas of the general basic type, but which appear more and more feldspathic, or less basic, in proportion to the length of time which has elapsed since they ceased flowing, or in proportion to the time during which they have been exposed to atmospheric action.

It seems probable that a very long exposure of a doleritic lava to atmospheric action may result in the production of a rock very closely allied to syenite, and Dana refers to a rock of this kind, found on some of the very old volcanic islands of the Pacific Ocean. He says:

"On Bolabola Ellis found masses of rocks apparently composed of feldspar and quartz, and on Maulua, a species of granite is found in considerable abundance, along with a vesicular lava, and the basalt common to all the islands. These varieties of rock appear to resemble the syenite* of Tahiti, which is a crystalline feldspathic rock, very similar to a greyish-white feldspathic rock that was observed passing into basalt in New Holland." *

From all these considerations it seems probable that the more feldspathic rocks of oceanic volcanic islands may be often derived from the more basic lavas, first from the subsidence of the olivine, then, and also, by atmospheric action removing the bases after decomposing the basic minerals, and sometimes, but rarely, depositing quartz. The development of white feldspar crystals in the older basic rocks of the Hawaiian Islands seems on a somewhat general and inadequate review of them, to be probable, but we should be glad to

* Recently termed by Prof. Dana "or whitish granite—like dioryte." See ante note to p. 189.

* Geology of the U. S. Exploring Expedition, by J. D. Dana, p. 304.

see this subject taken up by a competent microscopist. What we consider is to be observed on the Hawaiian group, agrees with the general principles of Bischoff, and seems to present us with a practical example of the first stages of the gradual alteration of the universal basic magma into more silicated, and ultimately into granite rocks. *

SECTION 3.—*Coast lines and Craters of Oceanic Volcanic Islands tend to appear at regular distances on sets of parallel and intersecting lines running in determinate directions. Bearing of this fact on the thickness of the earth's crust, and on the nature of what is beneath it.*

Perhaps the most notable and interesting feature connected with the Hawaiian group, is the way in which the different islands, their coast lines and their craters approximately coincide with a series of three sets of parallel lines drawn almost exactly at a certain mean distance from each other, and at an angle of sixty degrees to each other.

Charles Darwin first called attention to many groups of oceanic volcanic islands, where the vents were more or less symmetrically arranged "on one line, or on a set of short parallel lines, intersecting at nearly right angles another line or set of lines." † Amongst them he instanced the Galapagos Islands, the Cape de Verde Islands and the Canary Islands.

Perhaps however, the Hawaiian group, which he did not visit, is the most perfect instance of this symmetrical arrangement of oceanic volcanic islands, their coast lines and their craters, which exists. The map of the group, plate II, is compiled from the official map of the

* See Appendix, on the relation between the age and the mineral composition of the volcanic and other rocks on the Pacific slope of North America and elsewhere, according to Baron von Richthofen, and its bearing on the general subject. Also, on the relation which exists between the minerals of the volcanoes of northern California, Oregon and Washington Territory; and those of the Hawaiian group.

† Geological Observations, London, 1851, chapter 6, p. 126.

Hawaiian group, by Mr. F. S. Dodge of the Survey Department. The three sets of parallel lines, twenty statute miles apart, and at angles of sixty degrees to each other, have been added to the map and exhibit the following phenomena.

The main coast lines of Hawaii and East Maui, the main craters, and therefore, the islands themselves, are found to coincide in a marked manner with the three sets of parallel lines, drawn about twenty miles apart and at an angle of sixty degrees to each other. It shows all the main craters of the island of Hawaii to be at or near the intersections of the said lines, and if we assume the lines to represent fissures in the earth's crust, then the craters are at or near the intersections of at least two fissures, these being about twenty miles apart, making allowance for just such irregularities in one general direction as dykes and fissures in the earth's crust usually present.

East and West Maui, Molokai, Lanai and Kahoolawe to the westward, may be considered as representing the island of Hawaii and its main craters, on the supposition that it has become partially submerged. A depression of 5,000 to 6,000 feet would show Hawaii as four islands, of which the mountains of Mauna Loa, Hualalai, Mauna Kea and Kohala, would each constitute one. There is also a high portion of Mauna Loa, twenty miles southwest from the summit, and from which the main outflow of 1887 arose, which corresponds to Kahoolawe in relation to the mountain of Haleakala in the Maui group. Thus there may be said to be six main craters about twenty miles apart on Hawaii, and six main craters the same distance apart on the Maui group, and they all appear either at, or not far distant from, the intersection of two sets of lines, one drawn north and south true, and the other set drawn north sixty degrees east, these

same lines being at the same time parallel to two of the three sets of coast lines; while the third line is parallel to the third set of coast lines.

A similar relation between the coast lines, and the distances apart and the directions of the lines connecting the main craters, may be observed, but partially obliterated by subsidence and degradation, on Oahu, and on the three islands of the Kauai group.

It is evident that the whole group, which it will be remembered is entirely composed of the outpourings of basaltic lavas, is constructed on a fixed principle. This appears to be simply, that the main overflow of the lavas has occurred at the intersection of two sets of fissures, which existed about twenty miles apart, one set running north and south true, and one set north sixty degrees east.

There are three sets of lines, as shown by the map, and the third set of lines coincides with one of the three main coast lines of the principal islands—as the other two lines do with the other coast lines—as well as with the direction of the group, and many circumstances lead to the inference that there *may* be fissures in this direction, say north sixty degrees west, but it is evident that if a series of craters were situated at the intersections of two sets of fissures, one set running north and south true, and the other set running north sixty degrees east, and at exactly equal distances apart, they might be connected by another set of lines which would run north sixty degrees west. Whether, however, such a line represents a set of parallel fissures in the earth's crust twenty miles apart may be questionable. That a grand fissure, or bend, however, exists in this general direction, or in the direction of the Hawaiian group seems inevitable. The particular fissures which appear to have resulted in craters at their intersections, seem to be the north and south, and the north sixty degrees east fissures,

although these do not appear in one straight line through the whole group.

This seems to receive confirmation from the direction of the longer axis of the two great craters on Hawaii, Mokuaweoweo and Kilauea, and to some extent also from the figure of the immense crater of Haleakala, on Maui.

By reference to the map already referred to, it will be observed that the direction of the longer axis of the elliptical craters of Mokuaweoweo and Kilauea is north thirty degrees east, that is, exactly intermediate between a north and south fissure, and one running north sixty degrees east.

It is assumed that these two fissures, either are now, or have been, more or less full of white-hot molten lava, held there, as already explained, by the greater density of the cooler solid crust resting upon it. This molten matter would constantly tend to cool and solidify along the whole length of the fissures, but at the points of intersection, where the greatest mass of molten matter is accumulated, the heat would be longest retained, and the lava kept longest molten. Further, and this looks like a crucial test of the correctness of the assumed directions, the acute angles of the two fissures, which would necessarily come on a line running north thirty degrees east, would be melted off by the molten lava on each side of them, to a greater distance from the centre of intersection, than the obtuse angles of solid rock at the other two corners of these two fissures connected by a line running north sixty degrees west, thus tending to form a somewhat irregularly shaped elliptical crater, having its longer axis running north thirty degrees east, or on a line exactly at right angles to the trend of the range of the Hawaiian group.

This assumed condition of affairs may by understood at a glance by reference to the following sketch:

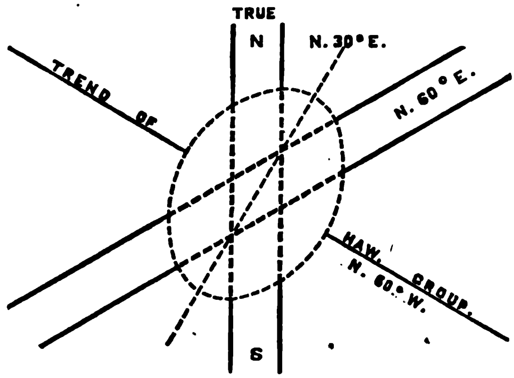

FIGURE 1.

It will be observed that when the solid corners of the intersecting fissures get melted off, there would be a much larger opening left at the intersection than at any other point of such fissures, and this would allow of another very impoitant and well understood physical principal to intervene to cause the points of intersection of two fissures to be the portions of fissure eruptions which remain longest active, or in other words, which retain the lava longest in a molten state. This principle is simply that the enlarged area allows of free convection currents from the universal molten substratum, which a simple fracture or comparatively narrow dyke, the sides of which are probably constantly tending to close, would not so well admit of. When the sides of a fissure full of molten lava come together, they might squeeze it all out, except perhaps, a narrow, irregular dyke of it, which might readily solidify, but at the points of intersection of two fissures where the projecting solid corners have been melted off, the sides could never come together, but would leave a large mass of still molten lava, kept hot by the lava in the intersecting fissure or the remains of it, as well as by convection from below.

Dana long ago observed that pit craters were the points on fissures that remained the longest open or full

of molten lava. The facts on Hawaii indicate that these craters are the points of intersection of two fissures, and similar facts are observable in a large number of the volcanoes of the earth.

Mr. Wm. T. Brigham * has called attention to the fact that the major axes of a great many craters of the earth lie at right angles to the trend of the range of mountains on which the craters are situated † and he brings forward the great craters on Hawaii as special instances.

By referring to the map of the group, plate II, and the diagram, figure 1, p. 148, showing the theoretical formation of the two great craters on Hawaii, it will be seen that not only is the direction of the longer axes of the craters at right angles to the trend of the group a literal fact, but the precise and definite reasons why it is so, are exhibited. ‡

The three sets of lines running north and south, north sixty degrees east, and north sixty degrees west, with which the main phisiographic features of the Hawaiian group coincide, are precisely those three lines which coincide with, or are at least, parallel to, the three sides of the equilateral spherical triangle which would be formed

* Notes on the Volcanoes of the Hawaiian Islands, by Wm. T. Brigham, Boston, 1868, page 107.

† In the published letter which I addressed Mr. Brigham, in 1877, already referred to, I overlooked the very important fact, that the longer axes of the two great craters of Hawaii are at right angles to the trend of the group. This oversight arose partly however, from Mr. Brigham having called the line of the Hawaiian group east-west and the major axes of the craters north-south, which, although well enough in a general sense, is not strictly correct. W. L. G.

‡ With reference to *pit craters*, such as Mokuaweoweo and Kilauea remain to this day, we would observe that tufa, or any other craters, are often merely a modification, or further development of pit craters at the intersection of two fissures. The top of Mauna Kea, on Hawaii, is covered with little mountains of tufaceous material. It seems to be a pit crater filled up, probably by the access of large quantities of water to the partly cooled molten lavas at the intersection of two fissures. Possibly the very access of a large quantity of water to such expiring molten lavas may have given the finishing stroke (for the present) to this now so-called extinct volcano. The water may accumulate in an expiring volcanic crater, which would be evaporated as it fell, in an active one.

on the globe by the projection of planes through the centre and solid angles of the hexa-tetrahedron, or the lines forming Elie de Beaumont's *Reseau Triangulaire.*

But this trend of north sixty degrees west and a transverse system of islands and accidents, seems to be common to most of the principal oceanic island groups. The following are the trends, as given by J. D. Dana * of some of the main Pacific oceanic groups:

	Course.
Hawaiian Range	N. 64° W.
Marquesas Islands	N. 60° W.
Paumotu Archipelago	N. 60° W.
Tahitian or Society Islands	N. 62° W.
Hervey Islands	N. 65° W.
Samoan or Navigator's Islands	N. 68° W.

The Fanning's islands and Vakaafo group he shows with the same trend.

Of the Atlantic islands, Dana says: † "The Azores have a west-northwest trend, like the Hawaiian chain, and are partly in three lines, with evidences also of the transverse system. The Canaries, as von Buch has shown, present two courses at right angles with one another—a northwest and a northeast."

The remarkable volcanic archipelago of the Galapagos shows its islands and the principal craters to be on a series of parallel lines running at something near right angles to each other, and it was in considering this group that Charles Darwin first, as far as we are aware, made the important observation, "that the principal craters appear to lie on the points, where two sets of fissures cross each other." The paragraph in full reads as follows:

"*The direction of the fisssures of eruption.*—The volcanic orifices in this group, cannot be considered as indiscriminately scattered. Three great craters on Albemarle Island form a well marked line, extending northwest by

* Manual of Geology, by James D. Dana, New York, 1880, p. 31.

† *Ibid*, page 37.

north and southeast by south. Marlborough Island and the great crater on the rectangular projection of Albemarle Island, form a second parallel line. To the east Hood's Island and the islands and rocks between it and James' Island, form another nearly parallel line, which, when prolonged, includes Culpepper and Wenman Islands, lying seventy miles to the north. The other islands lying further eastward, form a less regular fourth line. Several of these islands, and the vents on Albemarle Island are so placed, that they likewise fall on a set of rudely parallel lines intersecting the former lines at right angles; so that the principal craters appear to lie on the points, where two sets of fissures cross each other." *

It may be further observed that these parallel lines, formed by the craters and islands of the Galapagos archipelago, are found to be approximately, like those of the Hawaiian group, twenty miles apart, and the centres of each crater, in each sub-group, are approximately twenty miles apart, thus exhibiting the same set of phenomena as the Hawaiian group.

A good chart of the numerous islands of the Fiji archipelago, exhibits an analogous set of facts. In fine, all the central *oceanic volcanic* groups of the world, as well as most of the coral island groups, which may be assumed to cover extinct volcanoes, indicate that the main volcanic vents are generally situated at the intersection of two sets of fissures, and approximately at a distance of twenty miles apart, or multiples of twenty. This coupled with the fact that many continents and continental islands constantly exhibit indications of two sets of transverse fissures about twenty miles apart † seems to be one of the most important of physiographic phenomena,

* Geological observations, by Charles Darwin, M.A. etc., London, 1851, page 115.

† See appendix, on terrestrial accidents about twenty miles apart, in different parts of the world.

inasmuch as grand fissures at about twenty miles apart, reaching to the molten substratum, indicate a limit to the thickness of the crust in which the fissures occur, for cracks arising from a breaking strain in any crust whatever, will have their distances apart governed by the thickness of that crust. It is probable on mechanical considerations, that the fractures will not be at a less distance apart than the thickness of the crust, whilst if this is a frangible one, in proportion to the strains acting to rupture it—as may fairly be assumed to be the case with the earth's crust—the distance apart of the fractures will probably be close up to the limit of the thickness of the crust fractured. * From all the indications so far adduced, the fissures referred to by Darwin, and in this chapter, extend to a universal molten substratum; and their distance apart—twenty miles—shows therefore the probable thickness of the crust fractured, a thickness which agrees well with the prevision of Beaumont and Darwin, and with the calculations of the Rev. O. Fisher and others, as well as with the probable melting temperature of highly basic lavas at that depth.†

The Galapagos Islands, the Canaries, and some other volcanic groups—but which are not very far from continents—do not appear to be wholly on the tetrahedral fissures, as the Hawaiian and other Pacific oceanic volcanic islands do, but on these and the polar circle and the ecliptic fissures like the continental islands. That is to say, one or two lines may be on polar circle fractures, and the transverse line may be on an ecliptic fracture, at right angles to one of the other two, especially when in tropical regions, or, the third line may be on a tetrahedral fissure. These facts, however, are in

* All these deductions result from the simple consideration that a cube of any crust whatever is the strongest possible piece bounded by straight lines or planes, or the form—so bounded—which offers the greatest resistance to fracture in all directions.

† See appendix, on the melting temperature of rocks under pressure.

accord with the hypotheses of distinct sets of fractures for continental or inter-continental, and for central oceanic islands, for it may well occur that certain groups of islands, either those situated near continents or between the great regions of upheaval and subsidence, or in the wake of the great zone of the ecliptic fracture, may show their coast lines to be on both the continental and oceanic systems, or on certain lines of each.

It is evident from what we have so far adduced, that the normal figure of a continent, or of an island, is triangular, that is, bounded by three lines of fissures, but two triangles, or two sets of triangles, may unite and form a rhomboidal island, or both sets of fractures may unite in forming the different varieties of figure which we observe in fact. Erosion and subsidence are, however, great destroyers of the original forms. To point out instances of lands having this triangular figure, or other figure derived from these fixed lines of fracture, would be to go over the whole map of the world. Africa and Great Britain, North America and Tasmania, Italy and New Zealand,* Borneo and Gilolo, Hawaii and Fakaafo, are all constructed on plans distinctly referable to these principles, and to fractures running in the special directions indicated. These facts show how thoroughly the coast lines and other grand features of the earth's surface are outlined by joint internal and cosmical forces, which erosion merely modifies.

If this steady outpour of basaltic lavas during many past ages, at the intersection of certain fissures approximately twenty miles apart and in determinate directions, over different portions of the enormous area of the central Pacific Ocean, as well as over large areas of the other Oceans, be a great physiographic fact—and it

* If we take a map of New Zealand, and holding it to the light, we sketch the coast lines in pencil on the back, and then turn it upside down a remarkable resemblance to those of Italy appears. They are each on the two polar circle lines of fracture.

should be easily refuted if it be not—any theory of the earth's crust, which makes it other than thin and reposing on a universal molten substratum, will have to be fortified by much more reliable considerations than any hitherto advanced. A thin crust and a molten substratum becomes in the Pacific Ocean, as Charles Darwin inferred in South America and Captain Dutton in North America, almost "an observed fact," each observation having been made from a different point of view.

If the openings from which the molten matter had issued were found indiscriminately dotted about over the ocean, it would have left an opportunity to urge that these openings were over the pockets or separate reservoirs of molten matter which have been assumed to exist in the thick crust or in the solid earth, but when we find it appear almost invariably at what may be very safely designated the intersections of regular fissures, referable to great circles of the sphere, the hypothesis of local reservoirs must be abandoned, even if the grand continental and astronomical lines of lava-emitting fissures had not already obliged us to do so. The oceanic fissures, be it observed however, although not on such long and connected lines, show perhaps more regularity than the continental, both with regard to their distances apart and their determinate direction. In fine, the oceanic fissures are evidently independent earth-crust fissures like the continental, and the interior liquid has risen through them, wherever the intersection of two has given the basic cosmical magma beneath the crust an opportunity to do so. In coming to this conclusion regarding the molten substratum, it is of comparatively small importance what theory we may adopt regarding the cause of its expulsion to the surface, although the simple one of its having less mean density when it rises in a fissure than that of the crust which rests upon it, helps to explain not only the primary cause of modern

volcanic action, but also the injection into fissures in the crust of the molten matter below, as manifested in all past time and all regions, by the phenomena of dykes, sheets, laccoliths and lava-floods.

SECTION 4.—*Difference in the height of connected columns of molten matter, illustrated by Kilauea and Mauna Loa.*

On the hypothesis of a thin crust, supported by high columns of the less dense upper layer of the universal liquid substratum, how can we account for the columns of liquid, connected with each other, standing at different heights, and even in volcanoes which are close together. By the laws of hydrostatics we are told, all the columns of liquid should be the same height, and geologists often appeal, as a noted instance, to the two great columns of lava in Mokuaweoweo and Kilauea, situated only twenty miles apart, the lava in one of which, repeatedly stands, if it does not continually remain, some 10,000 feet above the level of the other, and both exhibiting very liquid and molten lavas in the bottom of the craters thus situated at very different elevations.

But when we duly consider the facts as they may fairly be assumed to exist in these great volcanoes, the probabilities seem to be rather the other way, namely, that the columns of molten liquid, although connected, should stand at different heights.

It is well understood that a difference of density would cause the different connected columns to stand at different heights. In order however, to familiarize the mind with the idea of liquid columns standing at different heights in openings in a floating crust, we may try a little experiment.

Take a piece of wood 6x6x2 inches deep and bore two half-inch holes through it in which insert glass tubes three inches long, just fitting the holes, flush on the lower side, and therefore projecting one inch on the upper side. Load the whole, say with lead at the bottom,

so that it will just float in water flush with the top of the wood. *

When thus floating, pour alcohol into one of the tubes until it has reached the bottom of the tube, when the level of the top of the alcohol will be found to stand about half an inch higher than the level of the top of the water. If oil be poured into the second tube till it is full to the bottom, the level of the top will not be half as high above the water as the level of the top of the alcohol. Experiments with liquids of varying specific gravity will show corresponding variations in the height of the liquid columns. With oils, and liquids that do not readily mix with water, this variation in the levels of the two columns will remain permanent for an indefinite time. It may also be noted here, what however, might have been predicted, that where the column in one tube is raised by pouring in a liquid of less specific gravity, the level of the column in the other tube does not rise or sympathize in any way, although there is a free liquid connection between the two columns.

It has already been shown that there is often a considerable difference of density in the lavas of Hawaii. † Whilst some of the basaltic glasses may be 2.70 and the feldspathic dykes, in an incipient crystalline state 2.90,

* Although it seems unnecessary to explain so minutely, what is so evident, it may be of use to show practically, how liquids of different densities may behave in openings in a floating crust.

† Some observers of the lavas on Mauna Loa have noted very compact or non-cellular lavas as existing towards the summit, and have assumed that they are not less dense than those lower down. The compactness of a lava, however, does not necessarily infer density, or high specific gravity. The Palolo dyke type of dolerite, commonly found, as Dana says, at the central parts of oceanic islands, is "without a trace of a cellule," but is of lower specific gravity than most of the porous lavas. Quite compact volcanic glass at the edge of a dyke, may be of less density than the more porous lava of its interior. Besides, the cellular, or the compact condition in which we may happen to find a solid lava, may be no indication of its condition as it rose in the fissure. A molten lava, free from gases, may become full of air cells under the effects of a fountain rising in the atmosphere, whilst, on the other hand, a frothy lava may, under certain circumstances, settle down so as to cool in the shape of compact basalt.

the ultra-basalts are often 3.10. This is in the cold solid state, and much larger differences in specific gravity may be expected when the feldspathic and basaltic lavas are in a molten state and at a very high temperature. A difference of ten per cent in density, seems quite within the possible range, and a column of molten lava twenty miles deep—which is the probable depth from various considerations—might thus be balanced by another column of lava of greater specific gravity of eighteen miles deep, both being connected with the same liquid substratum, leaving one standing steadily two miles above the other.

Although, as we have seen, Prof. J. D. Dana has urged that the great central bosses of basaltic islands often consist of a feldspathic rock of some ten per cent. less density (in the solid state) than the lavas of the outflows on the flanks of the same volcanoes ; yet without appealing to probable differences in the composition of the two columns of lava in order to produce the requisite difference in their specific gravity, we need only refer to the probable difference in temperature in two columns of lava having the same composition, to produce the requisite difference in their specific gravity.

To exhibit this we may try another little experiment, which, although it does not show anything that is not well known in physics, seems a useful one to illustrate the case of molten lavas rising in pipes or openings in the crust of the earth.

Take a closed metal box of any convenient size; insert glass tubes of different diameters fitting tightly into corresponding holes in the top of the box, say a 2½-inch, a 1-inch, and a ¼-inch tube, each say nine inches high. At the side of the box fasten an elbow slanting downwards, into which fix another glass tube say ¼-inch in diameter. Now pour into the box through one of the tubes any kind of easily congealing oil, or what we have found

most suitable for the experiment, molten stearine,* until the box and tubes are full, say to within two inches of the top. Arrange lamps underneath the metal box so as to keep up any desired heat less than boiling, and so that an equal heat may be communicated to the stearine in all parts of the box. When the stearine in the box gets well hot—under the boiling point—it will be found that its level stands steadily highest in the widest tube, and lowest in the two ¼-inch tubes, the level in the one connected with the elbow being lower than the one connected direct.

This is not an irregular or fitful effect, but the stearine stands steadily at their different levels as long as we desire to leave the apparatus in *statu quo.* It is evident that the stearine in the tubes has its temperature kept up mainly by convection currents (not steam currents), whilst the constant radiation and loss of heat is going on from each tube. The smaller the tube the greater the proportionate loss of heat; whilst at the same time the smaller the tube the less chance there is for convection currents to act to restore the heat lost, whilst they are almost entirely destroyed in the tube starting from the elbow. The expansion of the stearine is in some proportion to the temperature. The result is, that the liquid columns stand steadily at different heights, although *all have direct connection with the same homogeneous liquid having one temperature.*

Now if we may be allowed to suppose that the conduit connecting the crater of Mokuaweoweo—the main crater—with the molten substratum, is considerably wider at the same height than the conduit connecting Kilauea with the source of the molten lavas, we seem to require nothing more to account for the different levels at which they stand, for facility of convection would produce a

* The substance of which the so-called sperm candles are made in the United States.

great effect on the temperature and consequent expansion of the molten lava in the larger opening.

When an eruption breaks out towards the summit of Mauna Loa, and Kilauea many thousand feet below shows no sympathy by rising and overflowing, it is almost invariably assumed that the two columns cannot have any liquid connection. It is evident, however, from a consideration of the simple experiments just detailed, that a rise in the Mokuaweoweo column, from expansion by access of heat, caused by freer convection currents, might cause a large rise in the Mokuaweoweo column without affecting the Kilauea column a single inch.* There would be no necessity for their sympathizing.

But the probability is, that an outburst of lava towards the summit of Mauna Loa does not indicate any large rise in the Mokuaweoweo column of lava; but it seems more likely that the molten column in Mokuaweoweo—usually concealed from view—*stands constantly*, from its less density, some 10,000 feet above the level of the column in Kilauea. An eruption near the summit of Mauna Loa merely means that the constant, steady and gradual rise of lavas in the Mokuaweoweo column, and which we also see constantly goes on in the Kilauea column, has either burst through the bottom of the crater, or rent the mountain side. The only effect this could have on the lavas in Kilauea would be, if any, to lower them, so that those who look for a rise in the Kilauea column of lava when an outbreak occurs towards the summit of Mauna Loa may look for precisely the wrong effect.

It is an established feature in the behavior of the lavas in Kilauea for the last fifty years or so, that they steadily rise for some years and build up a mound of

* The simple crystallization and subsidence of the olivine in a great column of molten basic lava might relatively *raise* that column if connected with a universal basic substratum.

cooled lavas, like the gutterings from a candle, and which often overflow for some distance and fill up the lower pit of the crater. When the head of lava accumulates, so that the cone formed by it is sometimes nearly level with the edge of the great crater, it seems to be too much for the supporting power of the crust in the neighborhood, so that it breaks away at a lower level and overflows either the surface of the ground at some distance from Kilauea, or otherwise it breaks out in the bed of the neighboring ocean, both, generally on the line of the N. and S., or N. 60° E. fissures. At the same moment the level of the lava falls in the crater of Kilauea. The tube connecting with the hydrostatic bellows has ruptured towards the top and allowed some of the liquid contents to flow over its surface, and which tube, from the nature of the connection with the internal liquid mass, can only be re-filled very gradually.

We have before us a photograph of a panoramic view of the whole crater of Kilauea, taken in May, 1868, a month after the earthquake of April of the same year, when the level of the lavas in the lakes fell some 500 feet. The bottom of the great pit crater inside the black ledge at the same time subsided. The photograph shows clearly the whole phenomenon, the outer circumference of the great crater, the black ledge, the central depression with the great crack at the edge of the black ledge, and the two pits in the centre of the picture with the faint emissions of gases over them, in which the lava had just subsided. We have before us also an excellent panoramic photograph of the same scene in 1875—thanks to the kindness of the chief of the "Challenger" Expedition, the late Sir Wyville Thomson. This shows the solid lava in the neighborhood of the pits to be considerably raised, and a sea of consolidated molten lava which has run into the great central depression, and partially filled it up,

leaving a clearly-defined line against the edge of the black ledge, which only departs from a level line, in so much as it rises towards the two raised pits in the center of the picture, of Halemaumau and the South Lake. At this time the top of the mounds of lava formed near these lakes was still some hundreds of feet below the level of the edge of the great crater of Kilauea.

By the courtesy of Frederic Bonney, Esq., of Rugeley, Staffordshire, we have also before us a panoramic view of the crater of Kilauea, taken from very nearly the same position as the view taken in 1868. This was taken by Mr. Bonney in September, 1881, or over thirteen years after the first. The mound of lava around Halemaumau lake now overtopped the outer edge of the great crater, whilst the lava proceeding from it appears to have filled up the central depression, and has run over and obliterated the black ledge. This indicates a more or less steady and gradual rise of the lava in thirteen years of many hundreds of feet, but is only a repetition of what went on previous to the earthquake of 1868. A rupture and subsidence of these lavas in Kilauea is now looked for at any moment,* accompanied by an eruption of lava at some distance and at a lower level; but, as this sometimes occurs under the ocean, it may only manifest itself by great sea waves rushing inland, and a plentiful supply of par-boiled fish.

If, then, this steady secular rise of the molten lavas in Kilauea is indicated by observation, we may well believe from analogy that the lavas of the great central crater of Mauna Loa are also rising steadily at a similar gradual rate. Further, we have every reason to believe that the Mauna Loa lavas act like the Kilauea lavas, that is, they are not every now and then suddenly

* This was written nearly two years before the subsidence of March 6th, 1886.

thrown up from great depths, but that the level stands permanently in the fissure-conduit at great heights in Mauna Loa (just as the lava in Kilauea stands 3,000 to 4,000 feet above the sea level), but usually concealed from view by the cooled surface of the crater of Mokuaweoweo. As the lava gradually rises, the increasing strain at last ruptures the mountain or the summit crater bottom and relieves itself. A simple hydrostatic fountain of white hot and "super-fused"* lava is the result in one place or the other. That this continual rise and running over of the Mauna Loa lavas has been constantly going on for ages past is proved by the immense mass of the mountain itself, which is composed of a series of flows of solid lavas (more or less impregnated, however, with air bubbles), whilst strata of tufa and pumice may be almost said to be absent.

Can we conceive of any force more in accordance with this slow secular rise of molten matter in these Hawaiian volcanoes than the slow subsidence of the earth's crust into it—the subsidence of the bed of the Pacific?

The record of the eruptions in the summit crater and on the sides during the last sixty-four years also indicates that the molten lava constantly stands at a great

* The term super-fused has been applied to the Hawaiian lavas by Capt. Dutton, and we quite agree with him that before being cooled off, they are much hotter than would be necessary to keep them simply molten, or in a flowing state.

It has sometimes been said that on the hypothesis of a cooling molten nucleus, convection currents would bring *the whole* to near the temperature of solidification before a crust would form. In this supposition the circumstance of the probable increasing density of the nucleus with depth seems to be over-looked, whether the density be increased by pressure or by the denser nature of the materials, or both. Bearing this in mind, the opening of a fissure in the earth's crust may allow of its being filled with super-fused lava, that is, with lava at a much higher temperature than would be necessary to fuse it. It has come up from a hot, deep, heavy and compressed stratum, leaving behind it, perhaps, some of the heavier ingredients. The expansion alone, however, would have some cooling effect; but all goes to show how very hot the inner strata of the earth's molten interior or molten superficial layer may be.

height in the interior of Mauna Loa, and is constantly and steadily rising.

The great outpour of 1859 from an opening at the intersection of two fissures about 3,000 feet below the summit also seems to prove this. When it first broke out the lava formed a fountain of white-hot highly liquid lava, which played steadily for many days, gradually lowering, however, till finally it simply ran over, flowing down the mountain under its own cooled crust without any sign of steam, vapor or gases proceeding from it from its source to the sea at Wainanalii, a distance of about forty miles. Here we watched this molten lava pouring into the sea for several hours. It ran over a low shelf about ten feet high, and extended perhaps 500 or 600 feet wide, and fell into the sea where it was about 20 or 30 feet deep. It came from under the crust in great red-hot flattened spheroidal masses, having something the appearance of masses of moderately thick porridge as it is poured from a saucepan. The spheroidal masses, however, being perhaps 10 feet to 15 feet wide, and 4 to 6 feet deep. There was no steam, vapor or gas whatever to be seen coming from this lava till it went under water. Indeed the first contact of the red-hot spheroids did not seem to produce a particle of steam, and it was only when each had gone under water and become partially cooled off, that a puff of steam rose above the surface.*

The molten lava from this 1859 opening 10,000 feet up on Mauna Loa, for several months quietly *ran over* without any visible steam, noise, earthquakes or commotion of any kind. The constant slow overflow, and the equally constant cooling, at last blocked up and sealed up the opening, so that as the lavas gradually rose, the next outburst occurred in a new place. But the circum-

* This is an effect to be anticipated from the well-known spheroidal condition assumed by water when in contact with a red-hot surface.

stances of this eruption are only a repetition of most of the eruptions which have occurred on Mauna Loa, in some instances more or less modified.

It has often been noticed that the lavas in the different pools or lakes of molten stone in the crater of Kilauea stand at different levels. Indeed two lakes close together separated only by a partition wall of rock have been noticed to vary the level of their surfaces unequally, to the extent of several feet, while the observers have been looking at them. The conclusion was arrived at that the apparently separated portions of the lake had no liquid connection.* This, however, does not at all follow; bearing in mind the possible great difference in temperature in two pools of molten lava, both being connected with one main source, but one of which may be connected with it by a wide and direct opening, and the other by a narrow and crooked one, by which means the temperature of the two masses of lava may be over 1000° apart, one mass may be "super-fused" and the other on the point of congealing, with corresponding differences of density.

It is, perhaps, on this principle that we may account for the circumstance that eruptions of lava sometimes occur around the walls of Kilauea, and in the small crater of Kilauea-*iki*, adjoining it, at considerably higher levels than the level of the lava in the crater. We have only to assume a difference in the temperature and in the expansion, say equal to ten per cent. of their relative density, to account, at the same time, for the lava in the Mokuaweoweo column standing two miles higher than that in Kilauea, and for the different heights to which the hotter lavas may rise in fissures adjoining Kilauea, for if they are poured out fifty feet above the level of

* This looks like a case of "reductio et absurdam" when applied to the proposition, that all molten lava columns, which are connected, must stand at the same level.

the lava in the open vent of Kilauea, this only requires the supposition that the two vents may be connected 500 feet below, if they burst out 100 feet higher they may be connected 1000 feet below, and so on. It should be remembered here that the Kilauea lakes are great cooling surfaces, in which a violent process of convection and cooling is continually going on, which cooling must necessarily be largely communicated to the connecting column of lava below them, and this may be another reason to be added to the difference in diameter and directness of the two great conduits of Kilauea and Mokuaweoweo, why the temperature of the lavas in the Kilauea column may remain constantly lower than in those which supply Mokuaweoweo, which is not a permanently open vent.*

SECTION 5.—*Lava Fountains. Eruptions in crater of Mokuaweoweo.*

Although the standing pools of molten lava in the crater of Kilauea, and the jets or fountains which arise from them, are very wonderful and interesting, and unmatched by any volcanic phenomena in the world—the great fountains of molten lava which burst out from the sides of Mauna Loa, and from the bottom of the central crater of Mokuaweoweo, and even from the very top of the mountain of Mauna Loa, are still more wonderful. These have often been described, and we can only add our testimony to that of almost all other observers, that they are simple fountains of molten lava. Captain C. E. Dutton, in the letter on Hawaiian volcanoes already referred to, published in the *American Journal of Science*, of March, 1883, speaks of these great eruptions as follows:

"The accounts given to me by many eye witnesses of these eruptions, recite observations which strike me as

* See appendix. A tabular statement of Hawaiian Eruptions and Remarks, with details and references, showing the probable nature of the connection between the lavas of Kilauea and Mauna Loa.

most extraordinary, though I cannot for a moment question the general truthfulness of these accounts attested by so many intelligent and credible witnesses. The general version is that they break out suddenly and without warning, and that the lava spouts upward in enormous fountains to a great altitude, which the various observers estimate all the way from five hundred to one thousand feet. How much of this may be attribued to incandescent steam and how much to optical illusion of one kind or another, it is impossible to say. But I cannot doubt the general testimony that these vast lava fountains do spout upward to a very considerable height and that the fires which are actually seen are mostly lavas."

The only steady fountain which we have had the good fortune to see was at the bottom of the summit crater of Mokuaweoweo, in June, 1873, which we visited with Miss Bird, and carefully watched for some hours, with a binocular, both by daylight and after dark. The fountain generally played to a height of from three hundred to four hundred feet, as estimated from the known depth of the crater, although some spires, or shoots would now and then rise to a greater altitude. The form of the fountain would constantly vary, sometimes being in the shape of a low rounded dome, then perhaps forming a sort of spire in centre, with a fountain in the form of a wheat sheaf on each side. Sometimes it would look like one great wheat sheaf. On this day the visible vapors or gases connected with this fountain were quite insignificant; by daylight we could see none, but at night-time the bright reflection from the molten lava made visible a light blue haze which quietly left it. Some observers of this same fountain, a few months before, and when it was much higher, reported that they heard the sound of escaping steam or gases. Some of them even believed that they heard the roar of escaping steam

or vapors, some time before they arrived at the edge of the crater. We enquired very particularly however, from one of the most intelligent of the party, and he assured us that there was no proof that the noise they heard was that of escaping steam or gases. I have sketches drawn by two of the party, which show little or no steam or gases. There were two noises however, which were very easily distinguishable, one was the dull roar of the fall of this fountain of heavy liquid, and the other was the metallic clink of the fall of the solidified lavas which were constantly taken up by the fountain and thrown on to the solid rocks at a little distance from it. Indeed these solid pieces and separate portions of the molten lava, which cooled in the air, formed a light falling veil over the dazzling lava fountain, and as it fell close round the sides, it formed a black level scum which floated on the lava lake, out of which the fountain arose. Whenever a more than usually solid mass of lava fell within the area of this lake, it seemed to force itself through the black, floating scoriaceous mass and make a golden splash of the white-hot lava beneath it.

From different parts of the crater, and away from the fountain, white fumes arose like those which often appear in Kilauea crater.

This night and for two nights previously, there was so little cloud, or condensed vapor above the edge of the crater, that it was not sufficient to reflect the light of the great molten fountain below. For weeks previously we had seen this reflected light, which indeed, was the only possible means by which a light in the bottom of the crater can be made visible to an eye situated outside of it, but below the level of its edge. The night before we left Kilauea, however, the light on the top of Mauna Loa was not to be seen, although the night was clear, and it was only when we got close to the crater that a light smoke could be seen drifting away from it, whilst the great fountain of molten rock was playing below.

There was indeed, nothing about this fountain that gave the impression of its having been produced by steam, incandescent or otherwise, or elastic vapors of any kind, but everything seemed to favor the idea of its being a simple hydrostatic effect, and as though a great artesian bore had been made to a stratum of molten rock, which had only been awaiting an opportunity to overflow.

Molten lava has often been seen to rise from cracks at the very summit of Mauna Loa, when the bottom of the crater of Mokuaweoweo remained undisturbed. This however, only agrees with the phenomena which have been observed about Kilauea, and in addition to the explanation suggested in that case—may merely mean that a free communication has been opened in those spots, whilst it has remained closed, or more restricted, at lower levels. Thus a strong fountain of water might proceed from an artesian bore situated on the top of a rise, whilst a small dribbling spring only, might proceed from the same stratum of water at a much lower level, on account of the narrowness and crookedness of the connecting fissures; indeed the water might not be able to make its appearance at the surface at all, until a free passage was made for it. The cooled and filled up bottom of the crater of Mokuaweoweo might form an obstruction to the rising lavas, whilst a fissure at the sides of it might offer a free passage to them to the flat top of the mountain.

SECTION 6.—*Volcanic Steam and Clouds. Volcanic Waterspouts. Arched Lava Streams, Hornitos, Pahoehoe, and A-a. Some Hawaiian Earthquakes probably caused by Steam. Distinction between Volcanic and Tectonic Earthquakes.*

With regard to incandescent steam, which Captain Dutton suggests as possibly representing to the eye a portion of these fountains, we may say, that we have never

seen, on Hawaii, at any of the eruptions of molten lava, anything like incandescent steam. The *illuminated* smoke, gases, or vapors, which reflected the white-hot lava below them, we saw in abundance at the crater of 1859, and they are quite common at Kilauea and elsewhere, but incandescent steam we have never recognized at any of them.

This may be the proper place to refer to the cloud which commonly forms, not only over Kilauea and other orifices of eruption on Hawaii, but also over those areas in a lava flow where large quantities of molten lava collect. There is very often a large quantity of smoke seen to arise from the orifices of eruption, and this often spreads out in the higher regions of the atmosphere. There was a column of smoke, perhaps five hundred feet wide and ten thousand feet high, arising from the orifice of 1859, when we pitched our tent alongside it and which continued for many weeks after the fountain of lava had ceased, but whilst the molten rock was still running over and down the mountain; but this smoke ceased months before the lava ceased overflowing.

But the clouds we speak of are not necessarily formed from visible smoke at all. They form above the molten lava at a considerable height, and seem to be mainly composed of condensed vapor of water.

We have an oil-painting by Mr. Furneaux of a remarkable cloud which was constantly observed from Hilo over a portion of the 1880–81 flow, and where an immense area of molten lava had become dammed up, forming a great lake of it. Also another oil-painting by Mr. Furneaux of the same region and cloud on which a waterspout had formed, and which were not at all uncommon there. These waterspouts would sometimes burst over the hot lava, and the water being evaporated, rises in steam.

It is a rough and ready method to account for these

clouds, to say that they are formed from the steam which escapes from the lava itself. But the evidence is that the lavas on Hawaii discharge no steam, and few gases—except the air they inhale—and in watching the 1880–81 flow as it was running, we could see no more evidences of steam rising from it than we could from any other molten lava, whether in the lakes of Kilauea, the flow of 1859, or the fountain of Mokuaweoweo in 1873. Smoke, vapors and gases seem to arise from the orifices of eruption, and orifices in the neighborhood of molten lavas on Hawaii, and not from the lavas themselves.

These hanging clouds over lava lakes seem to be easily accounted for, however, on the ordinary principles of the formation of clouds. A great column of heated air must necessarily form over the molten masses which heated air gradually rises by its expansion and less density; and, as it rises, it is replaced by fresh air from all round the column. Thus a high rising column of heated air is continually maintained over the molten matter, and as the moisture-laden trade winds—or if in a calm the moisture-laden air around them—is drawn in, the hotter air sucks up the moisture like a sponge, keeping it, however, in an invisible state. It is only when this heated and moisture-laden air rises into a cool stratum above that the excess of moisture is condensed and forms the cloud. When this cloud becomes supersaturated, or very dense, it tends to fall in vortex rings through the heated column below it, thus forming the waterspouts. These clouds seem to be formed on the same principle as any other clouds, except that in these places—that is over extensive lakes of molten lava—there is necessarily produced a constantly rising column of hot air, which constantly renews the cloud in one spot.* The cloud over the lake on the flow of 1880–81

* Another phase of the same principle is exhibited in the formation

was probably blackened and intensified by smoke and vapors from the burning woods.

There are two marked features in the two main classes of lava flows—which appear on the Hawaiian Islands as well as in other parts of the world—which are constantly attributed to the action of steam and gases, but which, in our view, have nothing to do with either. The two classes of flows are what are called in Hawaiian *a-a* and *pahoehoe*. The *a-a* (rough) looks like a great scoriaceous railway embankment, down the centre of which the lava continues to flow in a molten state, forming ultimately a solid arched crust over the molten part, and when the flow ceases the molten lava runs away, leaving the arched crust, which, however, when all becomes cold, constantly falls in from contraction, although often an arched cavern of miles in length is left.

It is constantly stated that this arched form is the result of the expanding vapors in the lava, but there is another evident mechanical cause for it, without appealing to vapors, which the evidence on Hawaii goes to show, are not there. It is a well known fact, which has been proved by experiment, that the surface of rapidly flowing rivers maintain an arched form, being higher at the centre than at the sides. This has been attributed, and no doubt correctly, to the fact that a descending column of water will be balanced by a shorter column of water which is not descending so rapidly.* This effect, although slight in a river, becomes

of the trade wind-clouds which "hang" on the weather side of all the Hawaiian mountains. Warm moisture-laden air creeps up the inclined and windward sides of the mountains till it arrives at a cooler stratum, when the previously invisible moisture becomes condensed. This cloud is being constantly dissipated, and as constantly renewed.

* This effect may be readily understood if we put, say a ten pound weight on a spring balance and then lower the spring balance rapidly, when we find that we take off from the weight shown. We have only to lower the whole at the same rate that a falling body would descend, to take off the whole weight from the spring balance, and from the hand which holds both.

much exaggerated in a molten lava stream; for not only does the friction of the sides retard the velocity of descent of the running lava there, compared with the velocity in the centre more than in water, but inasmuch also, as the lava cools more rapidly at the sides, it becomes viscous and flows much less rapidly on that account; besides, this very cooling also causes contraction and density, and enables the columns of molten matter at the sides to balance higher columns towards the centre.

The other class of lava flow is called *pahoehoe*, or what, we presume, Palmieri would call "lavas of united surface" in the Vesuvian lavas. The Hawaiian name means smooth surface. This class of lava we saw flowing from the *a-a* stream of 1859, showing that it is not a different kind of lava, but merely a different form taken under different circumstances of flowing. The lava seems to form *pahoehoe* when it is not in too great quantity, but runs out quietly. For instance, the stream that broke out from the *a-a* stream of 1859, while we were watching it, seemed first to form into a flattened spheroidal mass, the crust of which was constantly cooling, and the fresh supply of molten lava was as constantly increasing its size. At last a limit seemed to be arrived at between the retaining power of the cooling crust and the pressure of the column of liquid lava inside it, when the molten lava would break away from the lower edge of the dome and form another just like it and close to it, and so on. The molten lava from the *a-a* stream continually keeping up the supply and running from one to another, forming a succession of domes. In some places areas of square miles are covered with a succession of regular domes, most of which are hollow, and in many the top has disappeared.

These are no doubt the "*hornitos*" which Humboldt describes as having seen in Mexico, Darwin in the Gala-

pagos Islands, and other writers, elsewhere. They are generally attributed, either to the vapors in the lava, or to those which arise from the damp ground over which the lavas run. To this latter cause some of the "*hornitos*" on Hawaii have been especially attributed, but they are very plentiful on the flat lands on the lee side of Mauna Loa, where there is no wet or damp ground to produce such an effect, and which indeed, would probably not produce any such effect if it were there.

The domes we look upon, as above explained, as hydrostatic effects on a cooling spheroidal mass of lava. In the first place the lava tends to form great flattened spheroids, not so much because it is all viscous like porridge, which tends to pour in spheroidal masses, but because, the instant it is exposed to radiation, a tough skin, or pellicle forms on the surface, and holds the molten lava inside, whilst the constant new supply expands the whole equally in every direction. When the molten lava finally breaks away at the lower side, a portion of it runs out to form another spheroid, leaving the cooled crust of the partially hollow dome. When all is cold, cracks from contraction often occur in the dome, usually forming a five or six sided rent towards the top, leaving a sort of loosened keystone there, which sometimes falls in and sometimes remains. We feel satisfied that these "*hornitos*" and the central arches of the *a-a* streams, would be produced substantially as they occur, if there was no steam, water, air, or gas in the planet. They are both hydrostatic effects in a running and rapidly freezing liquid.

We cannot do better than present here, the remarks of Captain Dutton, bearing on these points in the *American Journal of Science*, * already quoted. He says:

"One of the most striking features of Mauna Loa is the almost total absence of cinder cones. There are a few

* March, 1883, page 222.

small piles of fragmental material, here and there, but they are mere apologies for cinder cones, and are very aberrant in their modes of aggregation, and in the character of component materials. Considering the portentous nature of these monstrous outbreaks, it is wonderful how little disturbance attends them. No earthquakes, no rending and shaking of the mountain, nor roar of escaping vapors, no vast clouds of steam, but simply a huge river of fiery lava, welling forth like water from a fountain, and flowing swiftly on its course down the mountain side. So far as I have ever heard, this quiet character of the eruptions, the absence of fragmental products, and the insignificant amount of elastic force exerted by escaping vapors, are without a parallel."

To the truth of all this as a common case we can bear ample testimony,* at the same time we must not forget that the 1868 eruption from the top and sides of Mauna Loa, was preceded and succeeded by as violent and continued earthquakes as perhaps were ever recorded in history, but they produced little loss of life because the region is comparatively uninhabited, and what people there were lived in grass huts and wooden houses.

These great shakings of the earth, however, in connection with lava eruptions on Hawaii seem to be entirely accidental. It was generally remarked that they occurred after a very rainy season, and would be a natural result of large quantities of surface water finding its way to molten lavas and to the hot rocks a short distance below, and which on our hypothesis are always there. But it is equally certain that these same molten lavas will constantly overflow on Mauna Loa independently of wet seasons or of rain, and without any noise or shaking of any kind. The cause of their rise is, as we have ex-

* It must not be forgotten that a simple hydrostatic lava fountain free from steam or vapors may produce a pumiceous and cinder-like cone, from the falling lavas mixed with air.

plained, probably hydrostatic. The earthquakes, explosions and so on, are accidents which may or may not accompany that rise. It may be merely an accident that the rise of the lavas in the volcanoes of the earth which have been most commonly observed, is complicated with the effects of the water which they happen to meet with. The loudest and most common explosions on Hawaii are caused by air which happens to get entrapped, covered, or cut off by molten lava, under which circumstances the intense heat soon causes an explosion, whilst the cells almost universal in the superficial scoria of the a-a streams as well as those so common in the pahoehoe streams, appear to be simply air cells which become entangled in the freezing liquid.

These Hawaiian earthquakes afford a good example of the class which has been termed local volcanic, in contra-distinction to those called *tectonic*, or mountain-making earthquakes, of which the Chilean earthquake of 1835, referred to in Chapter II., forms such a remarkable instance. It is evident, however, that the two classes may sometimes be united. The rise or the fall of molten lava columns may cause earthquakes, whilst *tectonic* earthquakes may produce the rise or the fall of columns of lava. On Hawaii, local earthquakes have been known to be caused by the fall of great masses of rock into the void formed by the sudden subsidence of the lava in the Kilauea lakes. Near Kilauea also, violent upward blows directly beneath the Volcano House, seem to have occurred through the sudden rise of lava in a closed fissure, acting like a liquid in a vacuum tube. But the modes are numerous in which the lava may be conceived to act to produce earthquakes, sometimes connected and sometimes not, with the tangential strains and pressures in the earth's crust; the opening and filling of a fissure, or the injection of the lava between nearly horizontal strata, being perhaps among the most common.

SECTION 7.—*Tufa Craters on the Hawaiian Islands.*

Notwithstanding the solid character of the great mass of the Hawaiian Islands, the result of the flow of basaltic lava streams,* there are a great many tufa craters scattered about the group which seem to be the result of the accidental contact of the molten lava with water, either fresh or salt. The top of Mauna Kea is covered with cones of a tufaceous character, or at any rate composed of material which has been thrown up into the air, and which has fallen in the form of comminuted basaltic lava. The upper portion of Mauna Kea has very much the appearance of a large basaltic pit crater which has been filled up by explosive ejections, and which have formed numerous cones now standing several hundred feet above the edge of the original pit crater. This seems to be a common feature in volcanoes in different parts of the world, and often seems to be indicative of a last stage of volcanic activity, or at any rate of a stage in which the volcanic action has for some time been declining, or, as we would suggest, in accordance with our general hypothesis, the containing volcanic cone became at last of sufficient strength to retain the molten column at the extreme balancing height, or of hydrostatic equilibrium with the crust, so that any further accession of height could only be produced by the access of rain-water or melted snow to the upper portions of the molten column and the formation of explosive cones. This process may well give the final quietus to a volcano.

* We would remark here that although scoriaceous *a-a* streams are so common on Hawaii on the surface, we are hardly ever able to observe a stream of similar old scoriaceous lava in section in the sides of the ravines. All the flows seem there to be more or less compact, with the exception, perhaps, of a thin stratum between each. As the *a-a* streams get successively overflowed by new ones, or by *pahoehoe* streams, the scoriaceous portion gets consolidated and partially remelted by the newer flows, for it must be remembered that the bed of an *a-a* stream is composed of more or less compact molten lava, and that it may run there for weeks or for months.

There are a number of perfectly-formed volcanic cones also of discrete material which have been thrown up over fissures radiating from the centre of Mauna Kea and on all sides of it, and which, perhaps, may be referred to the last stages of volcanic action on this mountain. There is one which is often visited by parties ascending the mountain, and the upper edge of which is very accessible. The interior shows a large and beautifully regular cup, whilst at the bottom in the centre is to be seen the usual little mound with its centre again hollowed and coated with what seems to be a red oxide of iron as if the steam had only finished its explosive action a few weeks back.

There are a great many genuine tufa craters along the sea coasts of the different islands, and more especially on the Island of Oahu. One can stand on Punchbowl—at the back of Honolulu—itself a tufa crater, and see six or seven more in different directions. The bulk of all these tufa craters together, however, is quite insignificant when compared with the mass of the island, and those on Oahu have evidently been formed long after the main volcanic action had ceased, and even after the island had suffered great denudation, and coral reefs had grown around it. They generally occur where basaltic dykes are seen to have risen near the sea coast at the level of the ocean. Diamond Head, five miles from Honolulu is a simple tufa crater which seems to have broken out through the coral reef. Immediately to the northward of Diamond Head, and on line with the great Palolo dykes already mentioned; and inland is a little pit-crater with flows of basalt only, showing that the same line of rupture will exhibit three distinct kinds of volcanic matter according to the circumstances. Thus in Palolo Valley, in the heart of the mountain, where the basic lava has been held in mass and quietly cooled, it shows to-day the quite com-

pact feldspathic dolerite alluded to above, the olivine having probably subsided. At the little pit-crater appears the usual olivine basalt in a succession of rather thin flows; and as one flow is separated from the other by a vesicular stratum caused by air bubbles, a section of a number of flows together have a laminated appearance like clinkstone. When a block of these flows, which have melted into each other, gets separated and suitably supported, it will ring like metal, and there is now a block on the road passing this crater—Telegraph Hill—which the natives have, for years past, made a point of striking with a stone as they passed; but the material is simply olivine-basalt. The Diamond Head crater, on the same line, rising out of the sea, is composed of genuine tufa in thin laminæ, the effect of the junction of sea water and molten lava, from which, however, a great deal of the olivine seems to have been thrown out in a separate state, and now appears mixed with the sand and coral rocks in the neighborhood.

Another form of tufa crater was formed in the sea, at the termination of the flow of 1868 at Kau, caused by the meeting of the molten olivine basalt and the ocean waters. The usual lava tunnel in this case kept on some distance under water, and finally the molten lavas appear to have spouted out by the pressure of the head of liquid behind them into the sea. Here was formed a tufa crater, which was so easily disintegrated, that the winds alone would cause little sand streams to run down the sides. In the cracks were deposited chloride of iron and other products, the result of the junction of molten basic lava with sea water. The grains of olivine were sometimes found converted into an opaque brick-red mineral. The effects of the contact of basic lava with sea-water were palpable.

We may observe here that red-hot molten lava will run under water and keep red-hot and molten almost

for a longer time than it will when exposed to the air. This has been observed by Mr. Furneaux and others at the 1880–1 flow. Whilst the lava remains red-hot, no visible steam is formed, and no commotion is made on the water. The red-hot lava and the cold water being, probably, separated by a thin stratum of water in the well known spheroidal state. This, with the water over it, is probably as bad a conductor of heat as air, and at the same time it prevents radiation. Thus the results which may follow the meeting of molten rock and water differ remarkably according to the particular mode of the contact.*

SECTION 8.—*Kilauea and Mokuaweoweo separate Volcanoes. Both Pit Craters, and a phase of Massive Eruptions, may represent the fundamental character of Vulcanism.*

Captain Dutton, in the article on Hawaiian volcanoes already quoted, remarks:

"It has been the custom to speak of Kilauea as being situated on the flanks of Mauna Loa, and to regard it as a mere appendage of that mountain. But it presents itself to me as a distinct volcano, having no more connection with Mauna Loa than Mauna Kea has." †

This indeed seems probable from the distance between the centres of the two craters, which is as near as possible twenty miles, and about the distance which we have seen exists from centre to centre of the great volcanic craters on the island of Hawaii and on Maui.

Kilauea seems to be an opening left at the intersection of two lines of fissure, whilst the crater of Mokuaweoweo is another opening at the intersection of two entirely different lines of fissure, as seen by the sketch map plate II.

Notwithstanding this, there seems to be nothing in any of the phenomena connected with either of these

* See appendix, Personal Reminiscences and General Remarks concerning Hawaiian Lavas, etc.

† *American Journal of Science*, March, 1883, page 221.

two craters, that militates against the view that they may both be connected with the same molten substratum, some twenty miles below, as we have already explained in detail. They both appear to be as Dana says of all *pit craters*, those portions of fissures where the lava remains molten. They may well be on fissures from which "massive eruptions" have proceeded, and which massive eruptions have been held by Richthofen and others to represent the grand fundamental character of vulcanism, modern volcanic cones being regarded merely as parasitic excrescences on the subterranean lava-reservoirs, very much in the relation of minor cinder cones to their parent volcano." *

It would appear indeed, that the oceanic volcanic islands may represent the fundamental character of vulcanism better than the volcanoes of continents and continental islands do, because they appear not to be complicated with the upheaval, folding and crushing of sedimentary strata, or with their re-fusion or metamorphism.

SECTION 9.—*Continental and Oceanic Volcanoes. Continental and Oceanic Islands in connection with the question of the permanence of continents and oceans.*

We are now brought to the consideration of the distinction between continental and oceanic volcanoes and their parent fissures, which we have already intimated in Chapter III. seems to exist, and which distinction has been alluded to by the Rev. O. Fisher and other writers. Volcanoes as we have been considering them, are substantially the result of the rise of the molten substratum to the surface of the denser crust of the earth and of its extravasation through fissures in that crust already made, by the play of forces acting in the general tetrahedral collapse, and as affected also by the earth's rotation and by the attraction of the heavenly bodies on

* Text Book of Geology, by Archibald Geike, London, 1882, p. 256.

the molten nucleus. That is to say, one proximate cause of a volcano is a fracture in the earth's crust, independent altogether of the volcano. It has already been shown (Chap. III. p. 43) that the position of the fractures producing the continental volcanoes is probably determined by the position of the bend between the oceanic depressions and the continents, although the force which determined the precise direction of the continental* and inter-continental fractures, was the the luni-solar internal tide-waves. The central portions of the oceanic depressions do not seem to have been notably affected by the same force—as indeed theoretically they should not—but rather to have been fractured along lines parallel to planes drawn through the crystalline edges of the six-faced tetrahedron and produced on to a sphere. The oceanic fractures then—and the volcanoes along them—may be looked upon as those normally produced by the tetrahedral collapse—with the exceptions noted in Section 3—whilst the continental fractures are produced abnormally, so to speak, by the attraction of the sun and moon on the molten nucleus; which thus tends, as we have before explained, to split the thin crust of the earth in halves, in one set of planes parallel to the ecliptic, and in another set of planes at right angles to these, and therefore tangent to the two polar circles. The volcanoes follow the fractures.

We may thus expect to find that the continental fractures are superposed upon the general tetrahedral fractures, and also that when the two sets of fractures happen to run nearly in the same direction, one would control the other, and there seem to be indications of this being the case.

It must be borne in mind that the grand transverse

* In using the word continental in connection with the earth's general surface features, it must be remembered that the term embraces the submerged or partially submerged chains—or islands—which may be fairly shown to belong to the continents or areas of upheaval.

tetrahedral fractures would exhibit themselves in intertropical regions as running north 60 degrees east, and north 60 degrees west, in accordance with the actual lines of oceanic fracture pointed out in Chapters III. and VI. But the ecliptic fractures produced by a totally distinct cause, would exhibit themselves in the equatorial part of the same regions in the direction of north 66½ degrees east, and north 66½ degrees west, or on planes at an angle to the equator of 23½ degrees, so that these apparently more powerful systems of fractures—at any rate in continental areas—would in these regions control the transverse tetrahedral fractures which would be on fissures at an angle of only 6½ degrees from them. As before observed, the fractures (not ecliptic) that may be due to the internal tide-wave at the equinoxes, are coincident with a meridian line, and therefore coincident also with the third tetrahedral line of fractures.

One great distinction which seems likely to occur between central oceanic and continental fissures, is, that the former would open from below and the latter from above. That is, that in the general play of the forces in the lateral compression of the crust, combined with the rupturing force of the internal tide waves, and of the rotating nucleus, the downward bending oceanic crust would tend to open from below, whilst the upward bending continental crust would tend to open from above. Thus the oceanic fissures would be plunged into the molten basic substratum, but with a general tendency, at the same time, to close above. The continental fissures on the other hand, would tend to close below and open avove, thus allowing large quantities of molten basalt to be partially shut off from the general substratum, to be acted upon by percolating surface water; segregating basic elements, depositing quartz, and generally producing those effects which have already been fully referred to, and are generally admitted to be due

to the access of water to molten rock, and which exhibit themselves almost exclusively on continental and intercontinental areas.

It is evident that the simple existence of large quantities of water above oceanic volcanic fissures, does not necessarily produce any of the effects that may be attributed to water in volcanic phenomena, for not only are the oceanic islands almost exclusively basaltic, but the Hawaiian active and more recent volcanoes emit what have been termed *ultra-basic* lavas, whilst the lavas of the rest of the group seem to have been originally of the same composition, but have lost bases and become more feldspathic by atmospheric action during long periods of time; and the Hawaiian group seems to be typical of all the oceanic volcanic islands. It has already been explained that water seems to play no important part—we might almost say no part whatever—in the dynamics of Hawaiian volcanoes, although it may do so in Hawaiian earthquakes.

These considerations help us to understand what constitutes the distinction, in a dynamical point of view, between an oceanic island and a continental island.

Mr. W. O. Crosby, in an article on the Origin of Continents, republished in the Geological Magazine,* has some very pertinent remarks on the general question, and has summarized some of the best arguments on both sides. He demurs to the proposition that oceanic islands are exclusively volcanic, by pointing to New Zealand, New Caledonia, Phillipine Islands and Spitzbergen, amongst the larger islands, and to the Seychelles, Solomon, Marquesas Islands and Kerquelen Island, amongst the smaller, as instances of islands situated some distance from continents, and yet not exclusively volcanic, many of them containing great masses of Palæozoic and Mesozoic rocks.

* June, 1883.

It is evident that if the Marquesas Islands contain representatives of the older stratified formations, the absolute distinction between oceanic and continental islands cannot be maintained; but the information is so contrary to all other reports on the geological character of that group, and so much opposed to the analogy of every other central oceanic island or group, that we ought to require full particulars and details before admitting that it contains representatives of the older stratified formations. Dumoulin says of them:

"Like all the oceanic lands the frame-work of the archipelago of Nukahiva, (the Marquesas Group), is entirely volcanic; the mountains present, on their summits, several ranges of basaltic columns, naked and denuded of verdure."*

All the other islands mentioned by Mr. Crosby as containing the old stratified deposits, but at some distance from any continent, may be shown to belong to the continental areas of the earth's surface rather than to the oceanic, if we examine their position on the two sets of tetrahedral maps of the world published in part 1 of the *Vestiges of the Molten Globe.*

New Zealand seems to belong to the southern half-continent of Australia, just as the Island of Madagascar belongs to the southern half-continent of Africa, and the Falkland Islands to the southern half-continent of South America. Each island or group is situated on the same side of each half-continent and well to the southward on that side, that is, they each hold the same respective position to the parent mass. They are therefore probably the results of the continent-forming principle, tangential pressure, of which there is no evidence in the central portions of oceans. New Caledonia and the Solomon Islands being in the range of the curved line connecting the Islands of the Eastern

* Marquesas Islands, Dumoulin, Paris, 1843.

Archipelago with the Asiatic Continent and New Zealand—a cause for which curved line has already been presented—these two groups of islands must be placed in the category of continental islands along with New Zealand, even if the formation of some of them should be purely volcanic. The Seychelles go with Madagascar as an appendage to the African continent, whilst Spitzbergen may well be considered as part of Europe, which appears to be very gradually submerged to the northward under the waters of the Arctic Ocean, this island being a higher portion remaining unsubmerged. The Phillipine Islands clearly belong to the great continental fissure and uplift connecting them with Japan, and both with Asia.*

Mr. T. Mellard Reade has recently called attention to the result of the German Expedition to South Georgia, "in the South Atlantic Ocean," and which island they find to be composed of clay-slate, Mr. Reade brings forward this fact as opposed to the theory of the "Permanence of Oceans and Continents." If we look at this group on an ordinary map of the world, on Mercator's projection, it appears to lie in the midst of a waste of waters, owing to the necessary exaggeration of the dimensions of the southern ocean area, but if we raise the south pole of a globe, and consider it in connection with an Antarctic Continent we perceive that if such a continent ever existed, having dimensions in proportion to the other existing continents, these islands may well be remaining peaks of it; degradation (which must have been enormous in such a region) having reduced the south polar continent to its present restricted area. It is nothing new to find granite, gneiss and other old formations, in the Antarctic regions, they have been found there whenever looked for. Our general theory requires a continent here, and the old rocks found everywhere in south

* See Maps, *Vestiges of the Molten Globe*, Part I., Plates I., II., III.

polar regions, and in these islands, are the proofs of its existence, when added to the vast area of land actually discovered.

Thus every island and group containing the older sedimentary strata, and which Mr. Crosby and Mr. Reade claim as oceanic islands, except the Marquesas group, is shown, in the light of the tetrahedral hypothesis, to belong to the continents, whilst the Marquesas group,* until something more definite to the contrary is offered, must be claimed as composed of strictly volcanic and basaltic islands. We may in the meantime safely rest the hypothesis on the purely volcanic nature of the Marquesas archipelago.

Mr. Crosby says that inasmuch as it is a generally accepted theory that mountains are formed by the horizontal mashing up of thick deposits of sediments, whilst there actually exist submarine mountain ranges, the application of this theory to them "is fatal to the notion that the oceanic abysses are permanent." We have already seen, however, that as in the case of the continuation of the Hawaiian group, central submarine mountain ranges may be nothing more than outpours of lava one over the other along lines of fissure, whilst there is no indication anywhere in mid-ocean to the contrary.

As far as regards the argument in favor of the permanence of continental and oceanic areas, derived from the circumstance that no abyssal deposits have been found in continental strata, Mr. Crosby seems to offer a question for consideration when he says: "In the ordinary sense, there are no abyssal sediments, but we

* As before remarked, if the Marquesas Islands actually show the old sedimentary strata upheaved, or any of the well known ancient rocks, the hypothesis of central oceanic volcanic islands alone loses its main support. It seems probable, however, that an old volcanic rock like the whitish granite-like diorite found by Dana in the central parts of dissected Tahiti may have misled those observers who have reported the old rocks as in existence in the dissected islands of the Marquesas group.

find over these oceanic wastes merely the impalpable dust which slowly settles, during the lapse of countless ages, from the limpid water of the central sea."

This, however, is merely negative, and would only show, if correct, that one of the arguments sometimes made use of in favor of the permanence of the ocean beds, should not be too much relied upon. We are, however, ignorant of the depth of this deposit of "impalpable dust."

Mr. Crosby further refers to what he considers "the rule, that volcanoes are situated upon or in the immediate neighborhood of thick deposits of recent sediments," that is to say, volcanoes "on the land." Therefore, he reasons: the volcanoes of the oceanic islands may also be expected to rest on sedimentary strata. Those central submarine chains which have been best studied, however, present themselves as simply volcanic ranges, and there seems to be no good reason why we should expect them to repose on sedimentary strata.

We have presented our general theory of the distribution of volcanoes. The great continental volcanic fissures are assumed to be on the line of the bend between the oceanic or the inter-continental sea depressions and the continental upheavals, caused, however, by the internal luni-solar tide-wave. The detritus washed from the upheaved land becomes deposited in the neighbourhood of the line of weakness at the bend between upheaval and depression, and as the tangential pressure pushes these sedimentary strata towards the continent, or towards the upheaved parts of the crust, new fissures may be formed on the same bend along lines at right angles to the direction of the pressure, which would become injected with the molten substratum; but no further necessary connection is shown between sediments and volcanoes, unless it be whatever effect may be due to the added weight of the sediments,

and although we must agree with Mr. Crosby and other geologists, "that sediments are in general a source of weakness rather than of strength in the crust, and may therefore help to determine lines of fracture, we cannot admit that this proposition "forms the basis of the origin of mountains," for mountains—or at least elevations—must have been in existence before the sediments could have been deposited.

Oceanic depressions, continents, mountain ranges of upheaved sediments, and the sediments themselves are, according to our hypothesis, either the direct or the proximate result of the quasi-geometrical collapse of the thin crust of the earth upon the contracting molten nucleus losing heat, both mutually accommodating their relatively altering dimensions, by approaching that regular figure which admits of the greatest extent of crust with the smallest volume of nucleus; and although the great opposing force of rotation constantly tends—and acts both gradually and paroxysmaly—to restore the original spheroidal figure, and to cause oscillations of the deformed crust, both continental and oceanic, it does not seem possible that this force could have reversed the position of the main areas of depression and upheaval which had once been inaugurated, founded, as they were from the first, upon a mathematical basis, and always tending to become more pronounced.

Bearing in mind these principles, continental islands would be all those that can be shown to be probably connected with the great areas of upheaval of the earth's surface, although these may be at some distance from the main continental shore lines, whilst oceanic islands whould be those which are situated towards the centre of the grand area of depression, and should be, if our general theory be true, exclusively volcanic.

That the central oceanic islands, or at least those not

covered with coral reefs, should be exclusively volcanic and basaltic, as far as is certainly known, occupying definite areas covering more than half of the earth's surface, is a most instructive physiographic phenomenon, pointing as it does, at the same time, to the permanence of the relative position of continents and oceans, to the probability of a universal molten substratum, and to the particular nature of that substratum; whilst the distance apart of the fissures and of the volcanoes in each group, points to a small limit of thickness for the solid crust.

It would be out of place to do more than briefly refer here, to the arguments in favor of the permanence of oceanic and continental areas, deduced from the geographical distribution of animals and plants, both in past geological epochs and at the present day. This subject may well be left to naturalists like A. R. Wallace, who, following Darwin, has shown the paramount influence of geographical features on that distribution.*

It may be remarked however, that placing before us Wallace's map† of the zoological regions of the world, we notice that the great zone of ecliptic fractures would approximately separate the three great southern zoological regions from the three northern ones, and that the divisions agree well with those of the tetrahedral collapse and shift. Northern Asia however, as might be expected, forms one division with Europe; whilst the northern part of Africa, which may be said to belong to the zone of ecliptic fractures, is included in the same division.

The absence of the large continental animals—except man—from oceanic islands, and their peculiarly insular

* Island Life, by A. R. Wallace, is largely a sustained argument both for the subsidence of the Pacific bed, and of the permanence of oceans, and one which cannot be easily disposed of. We leave the discussion of the question of a former Atlantic continent to Prof. Dana and others.

† Island Life, by Alfred Rusell Wallace, London, 1880, page 310.

flora and fauna, has been well pointed out by Wallace in the work just referred to.*

M. le Marquis G. de Saporta, in a recent article in the *Revue des Deux Mondes*,† on Prehistoric Man, suggests that the human race probably spread over the earth from a region all round the north polar circle, gradually advancing southward; following up his long entertained views of the origin and migration of plants and animals from the same region and in the same direction. In supporting these views, M. de Saporta avails himself of the tetrahedral hypothesis, and shows that as far as each goes, one hypothesis sustains the other, and both indicate the general permanence, throughout the past ages, of the grand continental and oceanic areas.

SECTION 10.—*On the evidences of upheaval and subsidence on the Hawaiian group, and their bearing on Darwin's Theory of Coral Reefs and Subsidence.*

If we examine a good chart of the Hawaiian group, including the islets, rocks and shoals to the north-westward, we observe indications of a more or less regular subsidence, increasing as we leave the Island of Hawaii and go north-westward. For, as we have already seen, the Maui group of islands appears to represent the Island of Hawaii partially submerged. Oahu again, has less area than Maui, and there are no outlying islands connected

* Mr. Wallace, from the point of view of the fauna and flora of New Zealand calls this group "anomalous" with regard to its character of continental or oceanic. From the physiographic point of view however, it is distinctly continental. The peculiarity of its plants and animals being the result of its former connection with the northern or tropical part of eastern Australia, and its subsequent separation. (See Island Life, by A. R. Wallace, pages 509, 510.) It was one of the "rides" or wrinkles of compression between the south Indian and the south Pacific Oceans, situated at the intersection of two polar circle fractures, on the border of the south Pacific depression. By the action of the earth's rotation on the general tetrahedral collapse, as explained in Chapters I, II and III, it became separated from Asia and from Australia, and is now left out in the water hemisphere, the advanced group of the south Asiatic or Australian continent, with a fauna and flora having both continental and oceanis features.

† May, 1883.

with it. Kauai has somewhat less area than Oahu, although the volcanoes which have formed it appear to have poured out greater quantities of lava, and it is a very massive island. It has two small islands, Niihau and Kaula, connected with it on one of the lines of fissure. About one hundred and thirty miles further to the north-westward, and on the same line, appears Bird Island, a mere rock, but supposed to be composed of similar lava to the rest of the group. It is 800 feet high. It is well worthy of note here that the distance from the centre of Hawaii to the centre of the Maui group, there to the centre of Oahu, and from there to the centre of Kauai, are about equal. From the centre of Kauai to Bird Island is only a little longer distance, seeming to show that this group of volcanic islands is not only situated on parallel sets of fissures having the main volcanic vents at the intersection of two of those fissures about twenty miles apart, but that the groups of such regularly placed volcanoes tend to appear at regular distances apart along the grand volcanic line.

Continuing in the same slightly curved line north-westward from Bird Island, and at about the same distance as this is from Kauai, we come to Necker Island, composed entirely of coral 280 feet high, and from one a half to two miles long. An extensive shoal is connected with this island. Again in the same line and direction we come to French Frigate Shoal, with a very small coral islet. Still in the same direction, but a little to the northward of the general line, appear a series of coral islands, reefs and shoals, ending in the Pearl and Hermes reef, Midway Island and Ocean Island, the two latter of which are genuine lagoon islands, and are on Darwin's theory, the evidence of the general subsidence of the ocean bed in that direction, and are colored blue on his map accordingly.

The fringing reefs around the Hawaiian volcanic isl-

ands bear evidence to the same effect, for there is a greater extent of reef rock round Maui and Molokai than round Hawaii, and there is still more round Oahu. With regard to the south-eastern portion of Hawaii, we have to remember that the constant outpour of basalt has tended to obliterate or cover the coral reefs as fast as they were formed.

When, however, we consider the evidences of upheaval on these different islands, these appear to show the greatest upheaval in the direction—for some distance at least—that we have just said, show evidences of the greatest subsidence. This looks at first glance contradictory, but a little consideration shows that it is not so, for if we imagine a great general average subsidence, increasing in amount north-westward, with the Island of Hawaii for the stationary axis, we might reasonably expect that any reversal in the general downward movement might take place in the same manner but in the opposite direction; that is to say, the reverse movement of upheaval would be greatest to the north-west, where the greatest subsidence had been, and it would be reduced to nothing on Hawaii, the stationary axis, resembling the movement of a lid on its hinges. The total length of this string of volcanic islands, rocks, coral islands, shoals and lagoon islands from Hawaii to Ocean Island, is about 1,400 miles.

The evidences of upheaval, as far at least as they may be proved by marine strata, are mainly confined on the Island of Oahu to the remains of a coral reef adhering to the Waianae range of mountains at a height of 80 feet above the level of the sea, and of a raised coral reef flat nearly all round it.*

On the Island of Hawaii we are not aware of any marine strata visible much above the sea level, but in

* See Appendix, letter from W. D. Alexander, Hawaiian Surveyor-General, on the evidences of upheaval on the Hawaiian group.

the districts of Kau and Puna, or the regions connected with the active volcanoes of Mauna Loa and Kilauea, there are many evidences both of local upheaval and local subsidence. The most southern point of Hawaii for instance, and all the district between the flow of 1868 and Honuapo seems to have been upheaved at a fault, the escarpment of which now forms the boundary of the lower part of the flow of 1868, as, until the date of that flow, it consisted of fine pasture land without any appearance of recent lava flows, whilst the land on each side of the raised portion is covered for miles with comparatively recent black lava. The escarpment, which runs from the source of the flow of 1868, nearly parallel to the coast line and towards Kilauea, as well as in the opposite direction towards Kealakekua, seems also to have been produced by a fault, whilst many of the apparently recent lava streams on the depressed portion below it can be traced to the same fault, as if they had issued from a fissure there.* Great local subsidences have also occurred in these regions seaward of what we have called the escarpment. We have two oil paintings by Mr. Furneaux of a considerable tract at Puna, Hawaii, where the sea now rolls in great breakers which was land before the year 1868. The stumps of cocoanut trees are seen in the sea, and a whole grove seems to have partially subsided.

In 1868 also a lateral shift of about 18 feet along a newly-formed crack took place not far from Waiohinu, and extending many miles. The ground shifted laterally

* Captain Dutton refers, in his notice of Hawaiian volcanoes, to evidences of upheaval on Hawaii in the shape of old sea cliffs and beaches. We are not prepared to question these from careful examination, but we have always looked upon the interior cliffs as escarpments caused by faults, where the central mass of Mauna Loa has been raised or floated up bodily, and the issue of lava streams from the foot of these cliffs seems to corroborate this view. There is, however, an opportunity for a great deal of careful examination in all this intensely igneous region, and which, in many portions, has never been even traversed by a geologist.

along this crack just about the width of the road, so that as one traveled from Kona towards Waiohinu the left-hand side of the road showed itself in line with the right-hand side of the road on the opposite side of the crack.

We have spoken of the general subsidence increasing towards the north-west from the Island of Hawaii, and also have referred to the evidences of a small subsequent movement of upheaval, probably increasing as we go north-westward as far at least as Necker Island; for this raised coral island is higher than the raised coral reefs on the Waianae range on Oahu.

But besides the general evidences of subsidence of the Hawaiian Group deduced from their lessening area as we go north-westward, finishing in shoals and lagoon islands, which, after all, is perhaps only indirect evidence, the boring of a number of artesian wells of late years on Oahu has produced direct evidence of a subsidence far greater than the upheaval, which is indicated by direct evidence. A number of wells have been sunk in the neighborhood of Honolulu, mostly through the low flat of raised coral reef on which Honolulu is built, and which extends for many miles on each side of it. As might be expected, the further the wells are from the main lava rock of the island, the further they have to bore for water, for they all have to go entirely through the coral till they get to what they call hard, black rock, that is, to the compact basaltic lava streams of the group. For example, Mr. Dillingham's well, which may be said to be well inland, went through first about ninety feet of loam, gravel, boulders and clay. Then through forty feet of coral. Then sixty feet of clay. Then twenty feet of coral again. Then through clay, black sand and black rock about forty feet, when they struck flowing water, but continued to a total depth of three hundred feet still in black basalt, when they got a very

good flow and stopped. Mr. Ward's well may be taken as an example of one of those situated well out from the main volcanic rock and nearer the sea-shore. Their experience was as follows:

15 feet of loam and black and white sand; 180 feet of hard coral; 4 inches of white clay; 24 feet of coral and shells; 41 feet of yellow clay; 10 inches of hard coral; 109 feet of yellow clay; 23 feet of coral; 107 feet of white and yellow clay; 4 feet of quicksand; 4 feet of lava; 18 inches of hard grey rock; 30 feet of black rock, with three hard places and plenty of water.

The success of these wells, pretty well out towards the edge ot the sea induced Mr. James Campbell to bore for water outside of the extinct crater of Diamond Head, and not far from the sea beach, about five miles south-eastward from Honolulu. His experience was as follows:

	Feet.
Gravel and beach sand	50
Lava like that which forms the sides of the adjoining crater. (This in reality is tufa in thin layers)	270
Hard white coral like marble and without a break	505
Dark brown clay	75
Washed gravel	25
Red clay (very red)	95
Soft white coral	28
Soft rock of the character of soapstone	20
Brown clay with broken coral	110
Hard blue lava	45
Black clay	10
Red pipe clay	18
Porous lava rock	249
Total	1,500

No fresh water being found the boring was given up. The following memorandum is attached to this report:

"All the water found in surface wells in that neighborhood is brackish, and so was that obtained when Mr. Campbell's well was begun. This stood at about sea level in the well. The water finally met with, however, was very different to this, being actually as salt as brine, derived in all probability from the sea itself. This water

stood in the casing about one foot above the level of that in a surface well adjoining."

We may say here that Mr. S. G. Wilder started a boring on Hawaii, close to the sea, a few feet above its level, and in the usual basaltic rock of the Kohala district. He went down one thousand feet, and encountered nothing but the usual basalt rock of the district with intermediate clay layers, and finally stopped in hard basalt with olivine, the olivine blunting the edges of the boring tools. No fresh water was found, but brackish water remained in the bore all the time. *

Carbonized wood was found at a depth of two hundred and forty-five feet below one hundred and fifty feet of coral in Mr. Jaeger's well, on Oahu. †

Taken together the result of these borings seem to show that there has been a far greater subsidence on Oahu than of upheaval, and it is fair to presume that as we go north-westward we should find evidences of a still greater subsidence. In fine, that where we find in Charles Darwin's map, showing the distribution of coral reefs, (Geological Observations, London, 1851), that the Sandwich Islands proper, are tinted red, or as areas of upheaval, this may only refer to one of the later phases of movement, and is so far correct; but the facts lead to the question, whether the central portion of the Pacific should not be looked upon, on the whole, as an area of subsidence. Local upheavals, and even small general upheavals, at different periods in past ages, and up to

* It has been lately suggested that the Hawaiian group may consist of volcanic matter resting on a raised bank of limestone, that is merely "a whale-back of volcanic matter." The artesian borings, on the group, however, gives no countenance to this hypothesis. The lowest stratum has been invariably the usual hard black lava. Indeed, all the borings have stopped in this because experience has shown that in this stratum alone is flowing water obtained. What might be found at still greater depth than 1,000 to 1,500 feet, we know not, but as far as the evidence goes, there is no indication of a raised bank of limestone on which the group rests.

† We are indebted to W. D. Alexander, Hawaiian Surveyor-General, for these figures and the exact heights of some of the coral reefs.

the present day, do not militate against the idea of a general grand subsidence. Indeed, most great subsidences in all past geological time, seem to have been accompanied by more or less regular periods of limited upheaval. How far these latter appearances, may be due to actual upheaval, and how far to the withdrawal of the ocean waters by the deepening of their beds in other areas, and by the general lockup of water in the rocks, ice, snow, etc., it would be impossible to estimate.

Attempts have lately been made to show that Darwin's theory of subsidence is unnecessary to account for the facts exhibited by atolls and barrier reefs, and Prof. A. Geike in a communication to *Nature*, of November 29th and December 6th, 1883, on The Origin of Coral Reefs, brings together the considerations which have "reluctantly compelled him to admit that Darwin's theory can no longer be accepted as a complete solution of the problem of coral reefs." The main reason for this loss of confidence in Darwin's theory of the formation of atolls by subsidence, is the fact recently discovered by the *Challenger* and other deep-sea explorations, that the shallower portions of the ocean bed are constantly accumulating deposits of Globigerina ooze and other organisms, which may, in the course of time, build up those shallower parts to the surface. Then, as it is admitted, that the reef-building corals thrive best in the breakers, this tends to form encircling reefs, which gradually build outwards, leaving a hollow in the centre, which becomes, in time, further dissolved out and washed out, forming lagoon islands and barrier reefs. We do not pretend to discuss the details of this explanation of the origin of atolls and barrier reefs, which we leave to those naturalists who have made a special study of the subject. In the mean time it has an unsatisfactory look, compared with Darwin's theory,

as supplemented by the observations of Dana and others, and taking the whole facts together.*

The probability of the general subsidence of the great ocean beds rests on other evidence than that afforded by Darwin's theory of atolls and barrier reefs, although we look upon it as almost complete in accounting for the facts connected with them in the central Pacific ocean. The evidences we have brought forward also of the great probable subsidence of the Hawaiian group, heretofore considered as an instance of upheaval exclusively tend to confirm the theory of the general subsidence of the Pacific ocean bed. It should be remembered that a volcanic island like Hawaii may be increasing its height both by outpours of lava and by local upheavals of faults, whilst the bed of the ocean on which it rests may be steadily subsiding. We believe that considerable local upheavals on Hawaii have been caused by the lateral injection of molten lava—under a head of liquid—between the nearly horizontal lava strata (say at an angle of 6 to 8 degrees). †

Again, the continents on the ocean borders, and the main mountain ranges which define them, appear as a

*Professor James D. Dana has recently taken up the subject of the origin of "Coral Reefs and Islands" with special reference to the objections raised against Darwin's hypothesis. (See *American Journal of Science* of August and September, 1885). Here may be found a complete resume of the arguments, *pro* and *con*, by a geologist who is thoroughly versed in the subject. His conclusion is, that "Darwin's theory, therefore, remains as the theory that accounts for the origin of coral reefs and islands." Prof. Dana, in the final section of this article, adheres to his view and Darwin's, that the facts indicate a great "Central Pacific Subsidence." The facts which we refer to in the present chapter seem to lead towards the same conclusion. We would ca'l special attention to Prof. Dana's independent evidence on the subsidence of Central Pacific Islands, especially in the Marquesas Group, in *the existence of deep fiord-like indentations in the rocky coasts of islands, both of those inside of barriers and those not bordered by reefs.*" (See American Journal of Science, August, 1385, page 92). Also, "Corals and Coral Islands," pages 304 and 305.

† It has also been observed by Richthofen and other writers that the fissures under volcanic islands filled with molten matter may raise the general temperature of the rocks, and cause their expansion and elevation.

result of that subsidence, and approximately at right angles to a line drawn from the centre of each ocean. If we admit that the contraction of the earth's nucleus tends to change the spheroidal figure of the crust, the depressed ocean beds can hardly be anything but areas of subsidence, whatever local or partial upheavals they, or the volcanic islands raised upon them, may have undergone.

In the words of Prof. Geike, "the continents as we find them are the result of many successive uplifts, corresponding probably to concomitant depressions of the ocean bed."*

We would venture one further remark on the hypothesis that the central oceanic atolls—and which should be kept distinct from atolls on areas which can be shown to be connected with those of the continental uplifts—may be the result of deposits of organically formed detritus upon raised or shallower parts of the ocean beds. If we examine any good set of charts of the different groups of atolls, we notice that a number of them are far removed from being of that rounded or oval shape which submarine banks formed of discrete materials usually assume. Prof. Dana, in his work on Coral Reefs and Islands,† shows many maps of atolls, and at pages 168 and 273 he gives that of Fakaafo, or Bowditch Island, "as the type of the large part of coral islands." This atoll is not only triangular in shape, but has closely the outline of the Island of Hawaii. The maps of the Gilbert Islands, the Maldives and others in the same work show how large a number of atolls are sharply triangular in outline, which is the typical form of volcanic islands, wnen they have not been too much worn down by erosion and denudation. Further we find that groups of atolls tend to be about twenty miles apart, or multiples

* Text Book of Geology: New York, 1874.

† Page 912.

of twenty, just as we find groups of volcanic islands to be. It may perhaps be contended that the Globigerina ooze and other fine deposits, continually falling upon submarine volcanoes of this shape, would ultimately rise to the surface of the ocean in the same triangular, rhomboidal, or sharply polygonal shape, and show as atolls of that figure when the coral reefs had grown around them, but it seems inevitable that all sharp angles would be rounded off when the submarine volcanoes became covered thousands of feet thick by such soft mud as we know the bottom of the ocean to consist of, and the angular form would be obliterated. A subsiding angular volcanic island, on the other hand, would retain that figure as the hard coral reefs grew around it. It seems almost unnecessary however, in most cases, to urge this objection as opposed to the new theory of atolls, for as Darwin at first pointed out, the great steepness of the banks as shown by the great depth of water, close outside most of the central oceanic atolls—and we are not here concerned with the others—seems sufficient to dispose of the hypothesis of the rise of these oceanic atolls to the surface of the water by the deposit of mud on the top of partially raised portions of the deep ocean beds. The main data for the hypotheses seem to have been obtained in areas near to, or connected with the continents, and indeed may often be true of these, but may leave the hypothesis intact when applied to the atolls of the central ocean beds. If central oceanic islands, as is now generally admitted, are to be considered as distinct from continental islands, it is clear that the atolls in each region must also be considered separately, and in their respective classes. Let us repeat—the sharply triangular, and the angular atolls so numerously distributed over the deep ocean, cannot be the result of thick deposits of the oceanic ooze or mud on submarine banks or volcanoes, and which ooze is thus slowly raised from great depths at which the reef-forming corals will

not grow. If, however, these angular atolls are the result of growing coral reefs around subsiding volcanic islands, it would be absurd to look for a different origin for the rounded atolls near them, for there is no reason why this rounded form should not arise from the subsidence of volcanic islands, which had lost their angular figures by erosion, like Kauai, or Tahiti.

The oceanic atolls seem to be then, on general principles, what Darwin called them, monuments erected over departed lands, not *necessarily*, that such lands should have been continental, but volcanic islands formed by the outpour of one stream of basalt over another along lines of fissure. It is true Darwin referred to the subsidence in the Pacific having been *sufficient* to submerge continental plateaus, but he was among the first to call attention to the peculiarities of oceanic islands, namely, that they were all composed of basalt or coral, and that all had insular fauna and flora.

If the central but shallower parts of the ocean beds have been constantly receiving organic deposits which may raise them to the surface, and it seems as if they must have always been so receiving them, then the deeper parts of the ocean must always have been deep, or if once shallow, their beds then must have subsided faster than the deposits were formed. The last indeed seems to be the more probable hypothesis, whilst the shallow places in a general deep ocean may perhaps have been sometimes formed by volcanic eruptions, and afterwards built upon to some extent by organic deposits such as globigerina ooze.

Taking certain simple direct evidence alone for our guide, over the central Pacific, we might have arrived at the conclusion that it was an area of upheaval. The artesian borings on Oahu, however, in connection with the physiography of the group, tell another story, and remind us of Darwin's caution that subsidence tends to

conceal the evidence of such a movement. Between the constant deposition of volcanic and organic matter —to which so much attention has been lately called— we might expect the central Pacific to have been long since filled up, if the continued subsidence of its bed had not left it to-day—the Pacific Ocean. It exists, therefore, an evidence of the subsidence of its own bed, whilst the mountain ranges thrown up all round its borders at right angles to a line drawn towards the focus of that very subsidence confirm the testimony, even if Darwin's coral monuments had not been erected over the departed volcanic islands.

Those geologists who believe that the weight of accumulating sediments may cause subsidence—and if our general theory is correct, it must influence it—may have a case in point in the volcanic and organic * deposits of the ocean bed independently of those deposits found near the continental borders which are connected with the land-derived deposits. Such sediments may help to squeeze out the molten substratum which appears as volcanic outpours; but we require the deformation of the spheroid, and the resulting localized tangential strains to begin with—to form the land and the mountains and the first ocean beds; and when once begun, the upheavals and depressions must continue on the same main areas so long as the nucleus continues to contract faster than the crust. Denudation on the land and sedimentation in the ocean *only confirm or intensify these movements.* Continental volcanoes are on areas of general upheaval, which again are on the borders of areas of subsidence, but oceanic volcanoes are *on* the areas of general subsidence. The two facts are intelligible and in accord when we look upon volcanoes as the

* It has to be remembered that the materials of these organisms were not always suspended in the ocean waters, but are being continully supplied to them from the land and the atmosphere. They are, therefore, an added weight.

result of the weight of the bending crust, subject to tangential strains, resting on a molten substratum ; for the subsidence of an area may thus produce, at the same moment, upheaval and volcanoes on its borders, and volcanoes on its own subsiding area. It has been noticed, indeed, how local subsidences on continental areas have appeared to squeeze out the molten matter along the circumscribing fault fissures.* On the other hand, local upheavals may well occur on tracts or blocks between the fault fissures of generally subsiding volcanic areas by the injection of the molten matter between nearly horizontal strata, instead of its outpour over the surface. This may, in part, be the explanation of Darwin's observation, that the active oceanic volcanoes appear to be on areas of upheaval, whilst atolls are supposed to cover subsiding, but *extinct*, volcanoes. Extinct volcanoes retain no longer the machinery for producing local upheavals ; but, should their activity be renewed, it is, as we have seen, often accompanied by upheaval.

With regard to the Island of Hawaii, although the active end at the southeast shows evidences of both local upheavals and local subsidences, the old and extinct end at the northwest seems to have stood for many ages at the same level, judging by the bottoms of the great valleys of erosion of Waipio and Waimano, which are little above the sea level, for if the island had subsided, these should have been under water, and if recently upheaved, the bottoms of these valleys would have been steeper. We have called Hawaii, in the meantime, the stationary axis of a general area of subsidence increasing towards the northwest. Thus, Mauna Loa, Kilauea and Hualalai appear—in accordance with the general principle—as active volcanoes, in a general

* See "The Natural System of Volcanic Rocks," by Baron Richthofen, note to page 81. San Francisco, 1868.

subsiding area, on the borders of an area of greater and more recent subsidence. It would be a curious reflection, if we may ascribe any part of the portentous fiery lava fountains of these volcanoes to the accumulating deposit of the exuviæ of minute animal organisms in the ocean bed around them. The weight of these, however, along the line of 1,400 to 2,000 miles of coral reefs, shoals, atolls and subsidence which we have indicated, must be enormous, whilst the whole ocean bed in the neighborhood is more or less covered with organic remains to an unknown depth.

The tufaceous coast craters of Oahu seem to have been thrown up long after the main central volcanic action had ceased, and after the island had been worn down by denudation and had also subsided. Diamond Head crater, as we have seen, has broken out in the sea, and through five hundred feet of coral, or at least, of an organically formed deposit of coral and carbonate of lime with shells, three hundred and twenty feet from the surface. A basaltic dyke near by, is seen partly in the coral on the shore, and partly standing up like a wall in the sea, where the coral has been worn away by wave action. This more recent volcanic action seems also indicated on Maui and Kauai, so that it cannot be considered altogether local. It was accompanied or quickly succeeded by an upheaval of Oahu, and possibly of the other islands. On Oahu it seems to have amounted to an upheaval of about eighty feet above the present sea level. The coral reefs which must have been raised at the same time, appear to have been cut down to the present level of the sea by wave action leaving only fringes of *true* coral reef rock, clinging to the old lava rocks at a height of sixty to eighty feet above the sea. Here again we observe volcanic action connected with upheaval, whilst the previous period of subsidence was during a cessation of volcanic activity.

Thus extinct volcanic islands in the Pacific Ocean, and the atolls which may cover them, indicate subsidence, whilst a raised atoll or a raised oceanic island, although it may stand on an area of general subsidence, is evidence of volcanic action, which may be either consummated and visible as in the coast craters of Oahu, or as acting but not otherwise visibly consummated, as in the raised coral islands to the north-west.

The whole series of phenomena exhibited in the central Pacific Ocean indicate a general subsidence of its bed, with periods of local upheaval and volcanic action in different areas and usually along definite lines, thus lending support to the theory of Elie de Beaumont of the struggle between the deformation of the spheroid from contraction and collapse, and the continual effort of the earth's rotating fluid nucleus to preserve its normal figure; whilst all seem to be in accord with the detailed observations of Darwin, and with his theory of barrier reefs and atolls being the result of subsidence in —at least—the central portions of the great oceans.

SECTION 11.—*The Polynesian Race and Pacific Oceanic Islands in connection with the Subsidence of Archipelagoes with the Ocean beds.*

There are some circumstances connected with the occupation of the central oceanic islands of the Pacific by man which seem worthy of special note. They were peopled by one distinct race—the Polynesian. A people one in form, character, color and language, inhabit to-day the Hawaiian, Marquesan, Society, Paumotu, Gambier, Austral, Friendly and Navigator groups. This race must not only have had one common origin, but must have for ages been kept separate from and out of the influences of any other race. They seem to be as much a separate and independent stock (whatever that may mean), as Caucasians, Mongols, negroes, or the red races of America, although attempts have been made to

connect them with Malays or with East Indians, or with Aryans—and which connection, indeed, may be real.

The only continental Pacific islands which this race seems to occupy are those of the New Zealand group, and that was probably peopled from the Pacific oceanic islands. The space of ocean occupied by the oceanic groups we have mentioned, and peopled exclusively by Polynesians, is much larger than the whole of South America, and it has been sometimes suggested that they may be the remains of a subsided continent, the Polynesians having been the race which inhabited it; but Mr. Wallace and others have shown that these groups present no indication whatever of a continent ever having existed there.

And yet, here were these savages of one single race and language, distinct from any other, occupying an immense area of the ocean's surface, cut off from the rest of the world and, to a great extent, from each other. When first discovered the inhabitants of most of these groups knew nothing of the rest of the globe or of one another.

The subsidence of a great continent, however, should not, according to analogy, have left on the mountain tops a people speaking one language. If, for instance, South America had been largely submerged before it was occupied by Europeans, there would probably have been found a different variety of the American race, speaking a different language, on every group of mountain tops situated a few hundred miles from each other.

There has always seemed to be something mysterious connected with the peopling of these remote Pacific Islands by one race, and it does not much lessen the difficulty when we are told that the Hawaiians in ancient times made voyages in their canoes to Tahiti and back, a distance of about two thousand miles of open ocean.

Charles Darwin, however, made the suggestion which

seems to relieve us of many of the difficulties connected with the peopling of these groups, namely, that with the general subsidence of the bed of the central Pacific Ocean, a great many islands may have totally disappeared. He says: "Nor can I quite pass over the probability of the former existence of large archipelagoes of lofty islands, where now only rings of coral rock scarcely break the open expanse of the sea, throwing some light on the distribution of the inhabitants of the other high islands now left standing so immensely remote from each other in the midst of the great ocean." *

Dana has shown that the axis of the greatest Pacific subsidence appears along a north-west and south-east trend between the Hawaiian, the Fanning and the Marshall Islands, forming a wide blank of ocean without an island, which is near twenty degrees in breadth. He says: "Is it not then a legitimate conclusion that the subsidence which was least to the south, beyond the boundary line, and increased northward, was still greater or more rapid over this open area; that the subsidence which reduced the size of the islands about the equator to mere patches of reef, was further continued, and caused the total disappearance of islands over this part of the ocean?" †

If we may, with Darwin, connect this disappearance of great archipelagoes of central oceanic—and perhaps ultimately low coral—islands in the Pacific with the human epoch, there would be no difficulty in understanding how a people so expert in the water as the Polynesians could have formerly found their way from one group of islands to another when they were numerous, the original stock having in some way obtained a footing on any one of them. By this means also they

* Darwin's "Voyage of a Naturalist."

† "United States Exploring Expedition," Vol. 7, page 85.

would continue geographically connected together, whilst at the same time by the very conditions of their position on a central oceanic area they were removed from the influence of the invasion of other races from the continents or the continental islands, and were thus enabled to preserve their unique race characters intact over an area unexampled in extent anywhere else in the world.

This Polynesian race phenomenon, for we can call it nothing else, as interpreted from Darwin's point of view, indicates that the great subsidence of the bed of the Pacific ocean, which he was the first to point out, had probably been going on for a long period, has continued on a planetary scale, down to our own—the human epoch.

The primordial geometrical collapse of the earth's crust, which we have been attempting to follow through the ages, continues on the same lines to our own day, and whilst its particular effects are traceable in the earth's surface features and in the geographical distribution of the fossil remains in the strata of geological epochs long passed, as well as in the distribution of existing species, this earth-crust movement may still be exhibited—in the continual progress of secular refrigeration—in having directly affected the character and destiny of the Polynesian race; first by offering them great central archipelagos closely connected with each other and removed from continental influences, and then after submerging many groups, leaving their remaining dwelling places standing, "immensely remote from each other in the midst of the great ocean." The whole series of events in the progress of the tetrahedral collapse are thus—in accordance with Lyell's uniformitarian principle, referable to causes now in operation; for certainly neither the earth's rotation nor its loss of internal heat has ceased, whilst their definite effects have been shown

to be still proceeding. We may not relegate the grand movements of the earth's crust to principles of action operative in past ages alone. They continue in action up to the present hour. *

* We may call to mind here, that Charles Darwin first suggested that the habitations of the South American Indians, on the Andes, may have been gradually raised up into regions too inhospitable to continue to support life, (see Darwin's Voyage of a Naturalist, vol. II, p. 118, New York, 1846,) whilst he also first suggested that the dwelling places of the Polynesians may have subsided beneath the ocean. Man cannot, any more than the species that have preceded him, escape the effects of the oscillations of the earth's envelope; but these two cases appear especially noticeable, because the elevation of the Andes may be regarded as the result of the subsidence of the bed of the Pacific; and both together present in a striking light the grander movements of the earth's crust, due to secular refrigeration, which first defined the continents and oceans, and which movements have persistently continued on the same areas down to the present day.

CHAPTER VII.

THE PHYSIOGRAPHIC RECORD—A GENERAL SUMMARY.

En cherchant a coordiner les elements du vaste ensemble de caracteres par lesquels la main du temps a grave l'histoire du globe sur sa surface, on a trouve que les montagnes sonts les lettres majuscules de cette immense manuscrit, el que chaque *Systeme de Montagnes* en comprend un chapitre.—Elie de Beaumont.

Although every geologist will recognize how truly each system of mountains may be said to comprise a chapter in the history which the hand of time has engraved upon the surface of the globe, Elie de Beaumont was among the first and has been almost the only one since Von Buch, who was convinced that there existed a definite geometrical relation between the direction of the different systems of mountains; and that most of them appear on portions of certain great circles of the sphere, running in particular directions, or on lines parallel to them ; thus bringing the mountain systems and their direction into mathematical relation with the theory of secular refrigeration, and through that with the nebular hypothesis of La Place, which includes it.

The geological history of the earth, as related by the masters of the science, whilst it is an invaluable record of what has taken place during past ages in the solid crust, leaves the prime moving causes and dynamical relations of those events almost unnoticed. Beaumont however, directed attention to the particular effects which would result from cooling, contraction and col-

lapse, on a molten rotating spheroid; and to which he referred, not only the existence of continents and oceans, of mountain chains and their direction, but the phenomena also of active volcanoes.

It is true that the particular form of symmetry which he finally conceived that the relative direction of mountain chains indicated has not been established by further study and observation, as the basis of the figure which the earth's crust has assumed in the progress of secular refrigeration. It is to be observed however, that Beaumont appears, for some time before he fixed upon the *Symetrie Pentagonale*, to have contemplated the *Symetrie Quadrilaterale*,* as the geometrical basis of the figure in which the earth's crust collapsed. This figure includes, or is at least geometrically related to what he terms the *reseau triangulaire hemihedrique*, corresponding to the lines formed by planes passing through the centre and coinciding with the crystalline edges of a six-faced tetrahedron, produced on to a circumscribed sphere. The solid, in fine, that we have appealed to, as the geometrical basis of the secular deformation of the cooling and contracting spheroid.

The tetrahedral symmetry not only mathematically connects, as we have seen, the grand upward and downward bendings of the earth's crust with the cooling and contracting spheroid and with the direction of the main mountain ranges, but it furnishes the key to the cause of all the grander features of the earth's surface.

When we consider the different lines of reasoning which have lately appeared in geological works concerning the cause of the great bends in the earth's crust —the origin of continents and oceans—or the prevalence of the ocean in the southern hemisphere, and of the continents in the northern, we see that there is, to-day, no recognized basis for a science of dynamical geology.

* Notice sur les Systems de Montagnes, Paris, Tome 3, p. 1250.

For instance, the preponderance of ocean in the southern hemisphere—not long ago discussed in the pages of *Nature* and of the *Geological Magazine*—has been referred by three different writers of good repute to three different causes, namely: by one, to the attraction of a vast Antarctic ice-cap; by another, to the attraction of a dense mass of matter eccentrically placed in the interior of the earth; and by a third, to the attraction of heavier matter composing the bed of the southern ocean. All seem to agree that this great southern accumulation of water must be caused by a southward distribution of mass or weight which attracts it; all seeming to forget that, in that case, the Antarctic continent world be an astonishing projection of the earth's crust above this accumulated water, which would have to be accounted for as much as the excess of ocean in the southern regions, out of which it is seen to rise.*

Archdeacon Pratt accounted for continents and oceans by assuming a difference in the radial contraction of a solid earth, arising from differences in the conductivity in the strata under each, and consequent difference in loss of heat. The Rev. O. Fisher suggests as a speculation arising from G. H. Darwin's mathematical theories regarding the moon, that the ocean depressions may be the "scars" left by the matter which had been thrown off by centrifugal force to form the moon.†

* Most of these hypotheses of the excess of matter somewhere in the southern hemisphere, to account for the prevalence of ocean there, whether that excess of matter be on the Antarctic continent, in the ocean bed, or in the interior of the earth, seem to assume—as indeed geodesists have been in the habit of doing—that the surface of the oceans have the true figure of the spheroid of revolution due to the earth's rotation. This is destitute of proof, and indeed has now been given up. The evidence from pendulum experiments on oceanic islands tends to show that the surfaces of the great oceans are depressed at their central area below the surface of the figure, which would be due to the earth's rotation. Admitting that the oceanic crust may be more dense than the continental, this could only partially prevent the surface of the waters from following the depressions and heaping up towards the continents, from following, in fact, to a certain extent, the figure of the solid crust.

† *Nature*, January 12, 1882.

The hypothesis of the tetrahedral collapse not only proposes to account for the prevalence of ocean in the southern hemisphere, or three southern oceans, just where they exist, for the Antarctic continent itself, and for the three southern half-continents just where they appear; but for the position of the continents in the northern hemisphere at the same moment, while the Arctic Ocean belongs necessarily to the same hypothesis.

If read in the light of the hypothesis of the *tetrahedral* —instead of the dodecahedral—collapse of the spheroid, Elie de Beaumont presented the whole theory of the grand flexures of the earth's crust, the position of continents and oceans, and their connection with the direction of mountain ranges, in one short paragraph, in a manner which seems confined to Frenchmen and the French language. He says: "Ces bossellements generaux sont probablement le resultat et la manifestation de l'exces d'ampleur de l'ecorce comparativement au volume de la masse interne, et ils n'attendent pour diminuer que la formation d'une ride nouvelle dont leur influence combinee determinera la position." *

Why, with such an explanation of the existence, the shape and the relative position of oceans and continents —a simple sequence in the classic theory of secular refrigeration—should geologists or geographers seek for masses of matter arbitrarily distributed within or without the earth's crust, or appeal to equally arbitrary differences in the conductivity and contraction of different portions of the same spheroidal mass. Surely the subsidence of the ocean bed is a sufficient reason for the existence of an ocean, whilst the position of the axes of these oceanic subsidences, determines at the same time the position of the continents around them, and influences the direction of the mountain ranges which

* Notice sur les Systemes de Montagnes, page 1,245. Beaumont explains (*ibid* page 1,316) that *Systeme de rides* and *Systeme de Montagnes* are equivalent expressions.

controls the continental contours; and in this relation to each other they all appear.

We have seen, however, that after the tetrahedral symmetry had been inaugurated, and the earth had inclined its axis of rotation tweny-three and a half degrees, in response to the attractions of the sun and moon on the new figure, an entirely independent set of fractures were formed in the earth's crust, one set being parallel to the relative movement of the crest of the internal tide-wave, and the other set at right angles to that movement.

It seems probable that the derangement and complication which has been produced on the earth's surface features—as first outlined by the simple collapse of the crust—by these great astronomical fractures, was one reason why Beaumont abandoned the consideration of the quadrilateral symmetry, and looked for the geometrical bases of his mountain systems, in one which offered him a larger number of directions with which he could co-ordinate them. Indeed it seems somewhat remarkable to find that he expressly threw out of consideration astronomical causes, as influencing the direction of mountain chains. He says:

"L'absence de tout rapport direct entre la direction des chaines de montagnes, et la position des poles et de l'equateur, indique d'antre part a elle seule qui ces rides ne doivent pas leur origine a des phenomenes astronomiques reguliers." *

But if there is one circumstance more striking than another in connection with the grand accidents of the earth's surface features, it is the persistence with which many of the most important of them preserve directions parallel and at right angles to the plane of the ecliptic; in other words, having a direct relation to regular astronomical phenomena; so much so, that Prof. Guyot

* Notice sur les systemes de Montagnes, tome 2, page 779.

has laid it down as an axiom, that "*all the great mountain systems of the globe extend in one of two general directions, approximately at right angles to each other*," which he terms the *ecliptic* and *Arctic circle* directions.

Although these grand astronomical accidents are entirely distinct, in one sense, from the tetrahedral symmetry, they are brought into exact relation with it by three independent considerations. The first is, that the *position* of the polar circle fractures is on the borders of continental flexures referable to the tetrahedral collapse, and they result in mountain systems which are in accord with, or approximately at right angles to lines drawn from them towards the centres of the four oceans.

The second is, that the *direction* of *both* systems of fissures or fractures is determined by the inclination of the earth's axis, which is presented as the definite result of the change to the tetrahedral figure; whilst the third consideration is, that the very irregularities of one set of accidents—the polar circle set—that is their appearance to the eastward as they pass southward of the ecliptic set at right angles to them—have been shown to be mechanically connected with the same tetrahedral collapse, that is with the effect of the earth's rotation on three great subsided areas of the earth's crust in middle latitudes in the southern hemisphere, and *not elsewhere*.

Although Beaumont failed to recognize the connection of some of the grandest accidents of the earth's surface with astronomical causes, he has noticed the fact of this great break in the rectilinear direction of chains of mountains, and in a paragraph immediately following the one just quoted, says:

"Les chaines de montagnes ne presentent des relations evidentes que les unes avec les autres, par leur repartition en groupes rectilignes, a orientations connexes, et avec les dimensions du globe terrestre, par la propriete

que parait avoir chaque systeme d'embrasser plus on moins exactment une demi circonference de la terre." *

Beaumont then endeavors to explain this grand hemispherical break in the rectilinear direction of mountain ranges by showing what indeed is now generally recognized, that as the form of continents is determined by the mountain ranges, and the position of the mountain ranges by the ocean depressions, therefore the grand lines of terrestrial accidents, must be "*en rapport avec la disposition des terres et des mers.*" †

This however, leaves entirely unexplained why the continents, with the mountain ranges which define them —if to be looked for on great circles of the sphere—are found shifted out of line and to the eastward together, at a zone of fracture running precisely at right angles to their directions, and nearly separating the continents of the two hemispheres.

But besides the omission of the astronomical causes for some of the grander accidents visible in the earth's surface features, a prominently unsatisfactory part of Beaumont's special geometrical system, is, that it does not attempt to correlate the great oceanic depressions and the continental reliefs with the figure of his typical crystal, the pentágonal dodecahedron, although he appears to be fully alive to the importance of these fundamental features in determining the position and direction of mountain ranges—in explaining in fine the map of the world.

This co-ordination of the *bossellements generaux* with the figure of the first and simplest regular solid, forms the foundation of the tetrahedral hypothesis, at the same that it is pointed out that two grand astronomical systems of fractures at right angles to each other have disarranged on continental areas the fractures due to

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* *Ibid*, page 779.

† *Ibid*, page 780.

the simple collapse of the earth's crust, and that the grand zone of ecliptic fractures have allowed the crusts of the northern and southern hemispheres—affected by the earth's rotation—to appear separated from each other by inter-continental seas, and to be moved bodily in opposite directions along some of these ecliptic planes of fracture; and by which movement three half-continents—Europe, Asia and Africa—have been drawn together, and a fourth half-continent—South America—has been pushed near to the other three.*

The intensely volcanic character of this inter-continental zone of fracture, subsidence and shift, has already been alluded to, especially in the regions where the two systems of fissures intersect at right angles, and where the continents appear in consequence cut to pieces.

Almost while we write, the tremendous catastrophes in the Central American States, Spain, Greece, Ischia, and the Greek Islands and Java, exhibit the connection of volcanic disturbances with these grand systems of continental fissures. The regions around the three inter-continental seas—on this line of shift—seem to be affected together. A great earthquake or volcanic eruption on the borders of the Carribean Sea is repeated in the Mediterranean area or in the Eastern Archipelago. The slow secular subsidence of the beds of the three great southern oceans, affected by the earth's rotation, may have been the force that produced the concussions, the ruptures, and the volcanic ejections in the three corresponding regions of nodes of intersecting fissures, on one grand zone of terrestrial fracture, subsidence and shift, attended, perhaps, by a minute creep to the eastward of the whole floating crust of the southern hemisphere. A more remote force, however, such as a con-

* See Appendix: Is there a scientific basis for selecting any particular longitude for a universal prime meridian?

junction of the sun and moon, or of other heavenly bodies, acting upon the internal tide-wave, may have finally pulled the trigger that released the hammer in this delicately balanced system of forces, and determined each shock. Or, no especial exciting cause may have intervened, but it may have simply happened that segments of the earth's crust suddenly gave way, in each region, to the shearing strain to which our theory makes this zone continually liable, and which the three disasters along it—geologically-speaking simultaneous —indicate, may have arrived at the rupturing point.*

The picture of the earth's surface features, as delineated on any good globe arranged to exhibit the great circles of the tetrahedron, and the ecliptic and polar circle fractures, becomes a copy of a seismograph taken by a great self-recording instrment, as it—the earth—has rotated during the ages. These artificial circles represent the regular geometrical spacings on the sheet, by means of which the indications of the diagrams may be read.

By their help the important fact is demonstrated that all the grander lines engraved on the surface of the earth, and marked out by coast lines, mountain chains and active volcanoes, coincide with, or are parallel to, two planes at right angles to each other, one of which is the plane of the ecliptic, and the other is the plane which the shadow of the earth describes in a great circle around it—the line between daylight and dark—as the earth rotates *at the periods of the solstices;* the only periods of the year when the angle of the plane of that great circle shadow to the earth's axis of rotation, remains practically stationary for weeks together—indeed the only periods of the year when the angle of that

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* M. Ch. Lallemand has recognized the importance of considering this great inter-continental rupture and zone of shift as one of the main causes of earthquakes, in a paper read before the Paris Academy of Sciences, March, 1886.

plane to the earth's axis remains stationary for any portion of time whatever.

The seismograph thus spaced out indicates specially how and why the originally rectilinear great circle accidents on the earth's surface, tangent to the polar circles, and the continents on which they appear, have become warped and twisted together in a certain defined manner, and on either side of one plane at right angles to them and parallel to the ecliptic, by a succession of earthquakes along this zone, which appear to have been in more or less constant action for ages, and which continue with portentous frequency and violence to this day, and the moving cause for which, in the proper directions at the same time appears.

These artificial astronomically derived lines interpreted by the help of those formed by the crystalline edges of the tetrahedron and applied to the earth's surface features, not only point clearly and definitely to the necessary mechanical effects which have resulted during the past from the cooling and contracting of the earth's interior mass and the collapse of the crust—affected by rotation and the attraction of gravitation, internal and external—but they show why active volcanoes as well as earthquakes still prevail along these cosmical fractures —each being an independent but closely related effect— and that both occur most frequently where the two systems of fissures at right angles intersect each other on continental or partially submerged continental* areas.

* It should be noted that the Ural chain of mountains is anomolous amongst the great and distinctly marked chains on the earth's surface. It is the only important chain of mountains which preserves a distinctly north and south trend. It is not therefore on either a polar circle or an ecliptic fracture. But our general theory indicates that this chain was once near the central line of subsidence of the North Indian Ocean. Just where indeed we look for a great north and south tetrahedral fracture, along which have issued volcanic and igneous rocks, such as we find in the submarine chain down the centre of the Atlantic Ocean, but in the Urals, now more or less metamorphosed. The Urals are often termed an "igneous chain," but they possess besides, the attributes of a truly continental chain; that is, the old sedi-

All being the necessary outcome of the rotating molten spheroid first acquiring a solid crust and then losing internal heat as it revolved around the sun with its attendant satellite, and having its axis of rotation—originally at right angles to the plane of its orbit—tipped at an angle of twenty-three and one-half degrees to it, the definite result of the change to the tetrahedral modification of the spheroidal figure.

It has been pointed out that the internal cooling and the resulting earth-crust oscillations, foldings and shiftings, are probably still going on, on a grand scale but at a slow rate, instances of which have been referred to; but the researches of Mr. George H. Darwin remind us that just in proportion as we go back in time, so these various effects must have been more powerfully and rapidly accomplished. Not only must the earth—as has long been taught—have cooled and collapsed faster in its earlier periods, whilst the resulting subsidences, upheavals, and lateral shiftings must have been more rapid, but the nucleal tides must have been larger and more powerful, giving rise to those stupenduous polar and ecliptic rents in the earth's crust, of which we still distinctly observe the remains—many marked out by traces of active volcanoes. With a nearer and more rapidly revolving moon, acting upon and distorting the liquid nucleus and thin crust—which every theory of the earth

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mentary strata which had been deposited on either side, as if on a flat sea bottom, and often found unchanged, are in the Urals tilted up and metamorphosed. This chain, then, appears to have had a *special development*. First formed by volcanic ejections along a central oceanic north and south fracture, it became subsequently raised up by compression between Asia and Europe, and we may add, under the influence of the transverse tetrahedral line of upheaval, and acquired its continental character. The southern prolongation of this great north and south tetrahedral fracture and igneous outburst may perhaps be indicated in the long line of the Maldive and Laccedive Islands and the Chagos Bank in the Indian Ocean, but now covered with coral growths, as they have subsided with the cessation of volcanic activity. This southern prolongation is found, as all great southern prolongations are, shifted to the eastward, directly it appears to the southward of the great ecliptic zone of fracture.

admits to have most probably existed in early times—the mechanical effects that are here appealed to as the causes of the present condition of the earth's surface features, must have been more potent, and may safely be deemed sufficient, if the direction of the fissures and lines of movement show themselves to be mechanically in accord with the direction due to the mean luni-solar attractions upon the internal liquid or viscous spheroidal nucleus.

We have, however, further to remember, that with a constantly diminishing amount of energy in the prime movers, the gradual thickening of the crust may well have produced more violent or more marked exhibitions of that lessened energy. Thus a grand mountain upheaval in or about the Tertiary period, may be in strict accord with a general diminution of energy, whilst a great tertiary volcanic outburst may merely mean, that it was easier for the molten interior to rise in fissures in the crust and overflow the surface, than to raise that crust bodily, which had become too thick to bend readily with each change of level of the liquid; whilst in the continual cooling, both the relative density and thickening of the crust had increased, which required higher columns of the interior liquid to be raised above the surface to balance it, wherever the great fissures remained open.

These mechanical effects seem to have acted in each geological period together, in the great corresponding depressed and upheaved areas. The earth has collapsed "as a unit," as Prof. Dana has remarked, and with a certain geometrical precision. Whether we regard the great tertiary upheavals of the Alps, the Andes and the Himmalayas, or the oscillations of the Coal Measures in Europe, America and Australia, the different but analogous portions of the collapsing spheroid seem to have vibrated more or less in unison. Truly may we say with Beau-

mont: "Each system of mountains forms a chapter in the history of the globe," and which history is exhibited to-day, "in the vast assemblage of characters which the hand of time has engraved upon its surface."

One of the most important lessons taught by the study of the earth's surface features, in connection with volcanic phenomena is, that the latter mainly appear along fissures which are not caused by strictly volcanic forces, as usually understood, but along astronomically derived fractures. The great fissures which have permitted the escape of the lava, are not, as is often assumed, the result of volcanic action, unless we are prepared to include the internal luni-solar tidal enlongation of the molten spheroid in that definition. This is of prime importance to remember, and for those who admit it, a universal molten substratum becomes almost, as it has been termed, an observed fact; especially when we consider that the smaller density of the upper layer—a condition of itself almost certain, when it rises in a fissure—would necessarily cause it to appear above the surface of the crust whenever the fissures remained sufficiently open.

This molten substratum, or olivine-basalt, appears as a cosmical substance, and is specifically related to, if not identical with, the matter composing the bodies of space which have reached our earth, whilst the more siliceous, aluminous and hydrated minerals, lavas and rocks, seem to be the result of its decomposition by water, atmospheric action and re-crystallization, and do not appear in the extra-terrestrial bodies.*

* The prominence which nickel-iron takes in collections of meteorites leaves an impression that this substance is much more common in the bodies of space than in basic lavas, or in the interior of our earth; but it has to be remembered that when these bodies enter our atmosphere with planetary velocity, the feldspar, augite and olivine—particularly the first named, being in minute crystals—tends to be scattered in dust whilst the nickel-iron nucleus may reach the earth's surface entire. The fall of nickel-iron, however, is extremely rare compared with the observed falls of the stony meteorites. Besides, ancient falls of nickel-iron are more or less capable of identi-

On this hypothesis, minerals and rocks may offer to students a natural scheme of their formation, the facts and details for which appear to have been collected well in advance. The philosophic mineralogist seems to have an opportunity—by merely marshalling properly the known facts of his science—of presenting to the world a near complete account of the evolution of minerals and rocks from an ultra-basic magma in a state of igneous fusion; whilst, if this be the right key to that history, new and pertinent facts will continually present themselves as he proceeds with the investigation.

The geometrical collapse of the earth's solid crust on to the shrinking and molten interior in its various phases may be sufficient to account for the main phenomena of volcanic action, and for the steady rise and outpour of the less dense upper layer over the surface, through fissures largely produced by other causes, whilst the intermittent and irregular phases of volcanic action, including the great periodical outbursts of basalt may be the result both of the general play of the same forces in that crust and interior, and of the struggle between the effect of the secular cooling to deform the spheroid and that of the earth's rotation to restore that figure. The general permanence of continents and oceans, as well as the intermittent movements or the oscillations of the earth's crust, seem to be in strict accord with the hypothesis of a regular geometrical collapse subject to this reaction.

Indeed, this collapse from cooling and the reaction from rotation, so definitely suggested as probable by Elie de Beaumont—that is, the gradual deformation of the spheroid shown in the grand oceanic and continental

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cation as extra-terrestrial, whilst those of the stony ultra-basic minerals would not be. The presence of nickel-iron also in the earth's interior is shown by its presence in the transmuted basic igneous, or serpentine, rocks. (See ante-page 84.)

flexures and the periodical return of the crust to a figure nearer spheroidal under the influence of the earth's rotation—seems to be of primary importance when, considering the dynamical results of secular refrigeration. It seems to assist us in comprehending the cause of those great geological epochs registered in the earth's strata as having been long periods of comparative quiet, ending in disturbances which again preceded a new era of repose, whilst, at the same time, it postulates as part of the system, great periodical reactionary movements of subsidence and upheaval. It helps us also to understand why certain regions or strata appear to have been mainly affected by crushing strains or compression, whilst others have been mainly subject to tension* as if from the pressure of a liquid beneath, resulting in a true *sous-levement*, the rents in the crust having been filled at the same time with the molten basalt from below.

Although we have been mainly concerned with the effects of internal forces upon the earth's surface features, the immense influence of atmospheric erosion on the details of those features must be duly recognized, but this subject is usually so fully treated in all geological works, that we need not here consider it in detail. After all, erosion and sedimentation, imply upheaval and subsidence, as preliminary or concomitant operations, and just in proportion to their extent. The atmosphere can only wear down what the internal forces have thrust up, or left in relief. The earth's col-

* A good instance of this vertical rising and tension of a portion of the earth's crust is to be found in a paper by G. K. Gilbert, re-published in the *American Journal of Science* for January, 1884, on "Earthquakes of the Great Basin." It is only one out of many on the west coast of North as well as of South America, but is especially interesting because Mr. Gilbert refers it to an action now going on. It seems to be a smaller—and on that account probably a common—instance of hydrostatic vertical upheaval, such as Darwin describes as having occurred at the time of the great Chilean earthquake of 1835, already fully referred to and quoted ante Chapter II, page 22.

lapsing shell and the reacting nucleus have produced the prominences which the atmosphere immediately modifies by erosion, but the grand features remain distinctly visible in spite of it. Some of the most remarkable instances of erosion indeed, in all parts of the world, when for instance rivers appear as if they had cut through mountains of hard rocks, while an easier course seemed open to them on either side, are shown by Dutton and others to be the joint effects of erosion and the movement of the earth's crust. The latter is gradually raised up, as a sloping plane, against the saw represented by the flowing river, with its burden of grit, sand or gravel, whilst the mountain through which the river appears to have cut its way, has been subsequently carved out of the solid by erosive agents. The known effects of erosion on elevated lands are indeed, so stupendous, that they may well be appealed to, to prove the necessity for the continued action of the internal forces, otherwise the earth's land surface would have been brought long since to near the level of the ocean. *

The continual subsidence of the ocean beds however, must have been the most important agent in preserving the relative proportions of sea and land, whilst they are

* Some of the leading American geologists have recently been presenting elegantly reasoned papers on the geological phenomena of particular districts of the North American Continent, which have a world-wide application. G. K. Gilbert, in the Presidential address read before the American Society of Naturalists, at Boston, December, 27th, 1885, (and published in the *American Journal of Science* for April, 1886,) discusses in detail, the high degree of probability that the evaporation of the waters of the former great lake Bonneville, has caused the earth's crust over a defined area, to rise up in a dome-shape by the hydrostatic pressure of the molten mass beneath it, on the removal of the weight of the old lake waters; whilst Prof. Joseph Le Coute, in a paper presented to the National Academy of Science, April 24th, 1886, (and published in the *American Journal of Science* for September, 1886,) "On a Post-Tertiary Elevation of the Sierra Nevada," shows how erosion may be the *result* of elevation in many grand instances—not its cause, and how—this great Post-Tertiary upheaval seems to have extended along the whole Pacific North and South American coast as far as Chile; and he concludes by connecting this great recent—may we not say actual—continental uplift, with a contemporaneous subsidence of the Pacific ocean bed.

at the same time being covered by deposits, detritus washed from the land, volcanic ejections, and still more universally by deposits of the hard parts of organisms which extract the carbonate of lime and the silica which is in solution in the ocean water, but which is also derived, in the first place, from the land or from submarine volcanic ejection.

The tetrahedral collapse not only originated, but continued, and still acts in preserving, the relative proportions of land and water so necessary for the full development of organized life on the planet, whilst no part of the process is more important in this respect than the continued outpour of the *basic* nucleus, as M. Daubree has so well pointed out.

The Antarctic continent may perhaps be referred to as the one which, from its position in the centre of a region of storm, snow and ice, has suffered most in the struggle between the internal upheaving and the external degrading agencies. We may reasonably suspect the existence of a deep land-derived deposit over the bed of the three southern oceans wherever the icebergs from the Antarctic continent may have deposited their loads of detritus, whilst the reaction from the subsidence of the beds of the same three oceans may well be required to preserve what remains of the fourth great continent; a continent indeed, for the existence of which in such a situation it might seem difficult to suggest a reason from the point of view of final causes, although in the mechanical scheme it appears as a necessary part of the system. One benign result, however, of this conflict around the south pole, between fire and frost, between the powers of nature below and above the crust; is the cooling of the tropical oceans and of the tropical lands on their borders, which receive the benefit of the cool currents and the cool ocean breezes derived from Antarctic snows.

An immense number of the details of the action of the internal forces on the earth's crust have not been referred to. Indeed this may well be the province of each geologist in the district which he may specially study. Such reports as those of the American geologists on the Western States and Pacific Slope, open up new views of the action of the internal forces, and at the same time present grand and clear exhibitions of the results of erosion. Their accounts of mountain chains flanked by igneous outbursts of laccolites, lava floods, and of great oblong and triangular blocks of horizontal or slightly tilted strata, bounded by faults and fissures, along which the molten lava appears to have simply overflowed, are suggestive of the general principle of a univesal molten substratum all ready to rise in fissures wherever these may be produced by the general play of the forces acting on the earth's crust, and which fissures may continue as the outlets for more or less permanent overflows—volcanoes—so long as they or their points of intersection remain sufficiently open, or until they build up the conical mounds above them to a height and strength sufficient to confine a head of liquid which may hydrostatically balance the denser crust.

To whatever extent we may be prepared to admit the effects of erosion—and probably no geologist has yet defined the extreme limit of the changes which it has produced—we cannot shut our eyes to the fact that, when we contemplate the configuration of the surface of the lands, whether of continents, continental islands, or oceanic islands; the definite results of the internal forces reveal themselves everywhere, as well on a grand scale as in the details. That, in fine, the earth's surface features, earthquakes and volcanoes, appear to be due in the main to "the reaction between the molten interior and the solidified crust." This expression has sometimes been regarded as a vague one, but the more

the phenomena are studied, the more comprehensive and complete does Humboldt's concise definition of the cause of them appear.

The history of the cooling earth presents a well defined example of evolution or of progress from the simple to the complex, and in a more intelligible manner than that observed in organized beings, for the progressive changes in the earth's surface are seen to occur under the operation of the recognized primary laws of matter and motion. Our planet preserves also the analogy with the evolution of an organized body, inasmuch as the manifestations and progress of what may be called its life appear as part of a process ending in death. The earth was—from the necessarily limited mechanical point of view—brought into the condition of a planet under the influence of the action which has continued to develope it, and which seems destined to bring its active existence to an end, namely, the dissipation of heat.

APPENDIX.

APPENDIX TO CHAPTER I, PAGE 2.

On the Rigidity of the Earth deduced from the height of the Tides.

It has been assumed by Sir William Thomson, that granting the molten interior of the earth, it would be an incompressible liquid; but Professor Hennessy and other physicists have pointed out that it should rather be assumed to be a compressible liquid, and that there seems no *a priori* reason why it should be incompressible. It appears, however, equally important to consider that neither the earth's nucleus nor the crust may be truly spheroidal. If these may be assumed to be even slightly tetrahedroidal, it seems that this might change the conditions of the tide problem completely. Just what would be the effect of such a figure of the earth's crust and of the surface of the molten interior, either on the internal tides or the ocean tides, we cannot attempt to define, and we question whether any mathematician could follow the probable effects on the ocean tides on such a figure. It may be that the tides as they are now observed, are mainly the effect of the complicated movements of the earth's *crust*, which would probably result from a tidal elongation of the tetrahedrally modified spheroidal nucleus, moving—that is relatively—obliquely (at an angle, in a plane inclined 23½° to the equator,) in a shell of similar figure, but possibly unequally immersed in the fluid. That is, as has often been suggested, the tides may not be the direct effects of the attraction of the sun and moon on the waters of an ocean, resting on an almost unyielding and true spheroid, but they may be the indirect results of those attractions, both on the ocean waters, and on the somewhat complicated figure of the compressible nucleus, and of the flexible crust, such as we explain, on quite other grounds—to be that which probably exists. The tide problem seems to be too uncertain and complicated to rely upon as a means of settling the question of the solidity of the earth. It is clearly unsound, whatever other assumption may be made, in the anxiety to decide the question by mathematical demonstration, to assume a true spheroidal figure for it.

With reference to the condition of the earth's nucleus, assuming it to be in a molten state, we would suggest that the limit of its compressibility for a given temperature, may be reached at a comparatively small depth, so that it may be practically not further compressible but surrounded by a compressible layer. On this view the upper layer

of the earth's nucleus may be in a state ready to expand on the relief of pressure, and which condition seems predicable on other grounds.

APPENDIX TO CHAPTER I, PAGE 11.

On the forms assumed by collapsing envelopes, and their bearing on the figure of the earth—Carl Ritter on the deformation of the spheroid—Connection with dynamical geology—The uniformity of nature.

It has already been pointed out in the text how air-bubbles rising in water assume a tetrahedroidal form, and that many fruits and nuts having a hard skin or shell and a soft, moist interior, from which the moisture evaporates or condenses, tend to collapse in the same form; and that M. Lallemand, Engineer of Mines, believes that the little indiarubber balloons under compression would, with proper precautions, take the same figure.

We would here call attention to the microscopical forms which pollen grains, spores, etc., assume, and refer the reader to the "Micrographical Dictionary, page 314. Article "Tetraspores," of which it observes:

"They consist of an oblong or globular external cell or sac, at first filled with granular contents, subsequently separate into four portions called sporules, either by three transverse fissures or by two at right angles, cutting them into quarters like an orange, or by triradiate fissures which part them into the "tetrahedral" group, so often found in the division of spore and pollen cells."

See also "Hymenomycetes," page 390; "Ovule," page 567; "Polyembryony," page 622; "Pollen," pages 615, 617, 620. Also Leidenfrost's phenomenon. "Nature," April 11, 1878, page 466. Figures formed by a spheroid of water on a hot platinum crucible. See also "Transactions of the Paris Academy of Sciences," April 16, 1887: On the Thunder-storm of April 4th, 1867, by M. Godfrey, where figures of the hailstones are given, the form being that of a solid of revolution from "a spherical pyramid"—a tetrahedroid from a spheroid of revolution.

Professor Owen, of Tennessee, amongst various comparisons between the development of the earth and of animal and vegetable life, long since called attention to the "spherical tetrahedron" as the nucleus of the earth's features. See "Key to the Geology of the Globe," New York, 1857, pages 23 and 60. We should be careful not to discard entirely suggestions of this kind, because they are intermingled with fanciful, and even unsound, analogies. It is well understood that some of the great mathematical truths in astronomy have been brought to light by endeavoring to follow up a false analogy. Professor Owen discovered, or at any rate brought into prominent notice, the grand facts of the polar circle and ecliptic fractures; facts which are of paramount importance in any theory which professes to make intelligible the earth's grander surface features.

We have to remember also in trying to discover what figure the earth's crust would probably take under the influence of rotation, the attraction of gravitation, and the withdrawal of the fluid by contraction, that, as Herschel long ago pointed out, unless there was some cause acting to the contrary, an equal pressure on a spheroidal shell might be expected to still further flatten the earth at the two poles and produce "an annular equatorial continent." (See "Encyclopedia Britannica," article Physical Geography).

On the other hand, we have to remember that the amount of the elipticity of a true spheroid of revolution, as calculated for the rate of the earth's rotation, is all—as Beaumont has pointed out—contained within the thickness of the shell, assuming this to be not less than 26½ miles thick; that is to say, a true sphere is contained within the limits of thickness of such a shell, and which thickness bears about the proportion to the whole globe that the thickness of an egg-shell has to the egg—so that the point for consideration remains, whether the tendency in a spherical shell to collapse in a tetrahedroidal form, will or will not, overcome the tendency of the earth's spheroidal crust to collapse at the two poles. Seeing that the spheroidal figure is due to rotation, and that the tetrahedroidal figure, within certain limits, may possibly be a form of equilibrium; that is, compatible with *that very rate of rotation*, it seems to be quite probable that the earth might take the tetrahedroidal form rather than that of a spheroid more flattened, than would be due to its rate of rotation, and of which there is no indication. Some evidences of an excess of equatorial, or rather tropical, crumpling of the earth's crust have been pointed out by the Rev. O. Fisher and Mr. W. B. Taylor, but this has been referred to the effect of collapse of the shell on the diminished equatorial bulge produced by the retardation of the earth's rotation by tidal friction. (See Appendix.) Carl Ritter said long ago:

"Later investigations have determined that the spheroidal form is only an approximation to perfect accuracy, and that the earth is a polyhedron, whose exact number of sides has not been determined, and may prove indeterminable. Bessel has assigned, as the great task of science for the coming century to settle this question with perfect exactness; but what has been said is enough to indicate that in our knowledge, at present, there is certainly only progress, only approximation, no absolute exhaustion of the process of discovery." ("Comparative Geography," by Carl Ritter, Edinburgh and London, 1865). Again:

"The individuality of the Earth must be the watchword of re-created geography. To think of the Earth as a seed sown from the hand of God himself on the great fields of space, and filled with a germinant power of life, which will transform it more and more, and make it more and more worthy of its noblest inhabitant, is the first, as it is the last, idea which we must take and keep in these inquiries."

The basis of much of what we have to say on volcanic phenomena,

is, as we understand the problem, contained in the figure which a rotating spheroidal molten mass will take in the process of cooling, and after a certain thickness of crust is formed—cooling and contracting more rapidly in its interior fluid nucleus. The seed sown in space first takes a common seed form. In judging of this form we have not ventured into the details of the difficult domain of the geodesist, although we refer to his results, but we again take our cue from the words of the leading comparative geographer of the world—Carl Ritter—who says: *Ibid* p. 336.

"Besides this, which is really not a small point in consideration of the possible results which the minutest perturbation of one little planet may have on the universe, there is one other, more appreciable in its results—the probable influence of this spheroidal, or rather polyhedrous form, in producing the unequal division of land and water upon the surface of the earth. The apparent want of any principle or reason for this inequality has long perplexed geographers, and there seems to be no more satisfactory solution than the one to which I have just alluded. In the course of future investigations into the yet undetermined exact mathematical form of the earth, the law which controls the division into land and water will be more thoroughly understood. *Unquestionably the position of the great oceans depends upon their distance from the centre of the globe*; (the italics are ours), and although the present position of land and water seems fortuitous, undoubtedly it has a uniformly acting and thoroughly appreciable law."

If it be true as Carl Ritter affirms and as we believe, that the arrangement of the land and ocean on the earth's surface is the result of the first general deformation of the spheroid, without crushing or crumpling, the analysis of that particular arrangement of land and water, should give the clue at least to the particular deformation which the spheroid has undergone. This is what we have undertaken to discover in Part I., as epitomised in the first chapter of this volume. This may not necessarily, and in the first instance, be a task for the geodesist or the mathematician, but may yield to patience alone, just as the most difficult and complicated mechanical puzzle may be solved and pieced together by persistent experimental trials, or even by a lucky guess at the clue which had to be followed. It is for the geodesist to confirm or refute the correctness of the result at which we claim to have arrived. The earth was not finally and scientifically demonstrated to be globular until after a headstrong sailor had obstinately sailed round it. It was not then scientifically demonstrated to be a spheroid of revolution, until it was shown that a rotating globe *must be* compressed at the poles and bulged at the equator. The position of the land and water and the earth's surface features, show to the geographer that it cannot be strictly a spheroid of revolution. As we follow nature from the more simple to the more complex fea-

tures, so our difficulties increase and exact science remains for a time at fault.

Many of our physical geologists and geographers only get into difficulties when they begin to question the principles involved in Carl Ritter's explanation of the cause of the position of the continents and oceans, or, perhaps we should say, when they attempt to avoid that simple explanation.

The value of the principle of the *tetrahedral* deformation of the spheroid in the study of the dynamical geology, seems to be indicated by the circumstance that it supplies the depressing and upheaving forces where they are wanted, and explains at the same time why these geometrically derived forces seem to have acted—in the main—throughout all time in the same direction over certain great areas. Whilst the oceanic and continental areas seem to have been relatively permanent however, the earth's crust on these areas has been constantly oscillating under the influence of the earth's rotation which opposes the deforming agencies. But this effort of the rotating nucleus to restore the normal spheroidal figure can never be completed so long as the solid envelope remains too large to embrace the nucleus exactly. There is no geological evidence that the oceanic and the continental areas have changed places, and it is satisfactory to be able to point out a reason for it, and one which explains most of the earth's grand physiographic features at the same time. The special deforming power—subsidence of the sea-bed—resulting in upheaval round the borders, has always acted just where the geologist's observation of the facts require it to have so acted, but with continual oscillations or reactionary movements due to the equally constant but opposing force of rotation, and which reaction permits the four subsiding ocean-beds to return constantly to the work of crumpling and upheaving the crust in the old places, without exhibiting any greater amount of total secular deformation than at present appears. May not this subsidence with upheaval or collapse, and the subsequent partial restoration of figure or settling down—if we may so term it—of the earth's crust, have some discoverable relations with the periodical phenomena displayed in the strata at the close of geological epochs or at the commencement of new ones?

It seems worthy of note, that Alexander von Humboldt should have appealed to "the relative distribution of land and water on the surface of our globe, the configuration of continents and the elevation of mountain chains" (see Cosmos Vol. I., Sabine's translation) as instances of the *apparent* absence of law in natural phenomena, and places them in the same category as "the planetary system in its relation of absolute magnitude, relative position of the axis, density, time of rotation, and different degrees of eccentricity of the orbits;" all which *seem* to exhibit diversity rather than uniformity in nature, and a recent writer in "Nineteenth Century" on this subject quotes

these paragraphs and concludes that "from the point of view now under consideration there is no such thing as the uniformity of nature."

Does not this interpretation of Humboldt's remarks betray some confusion between two separate ideas? While all must agree in recognizing the uniformity of the laws of nature, all must admit the diversity of the results exhibited in the action of those uniform laws under different conditions. Laplace puts this in a clear light and in a few words in the quotation at the head of our first chapter, thus: "Infinitely varied in her effects nature is only simple in her causes, and her economy consists in producing a great number of phenomena often very complicated, by means of a small number of general laws." Who can doubt that the differences seen to exist amongst the planets, as well as the relative distribution of land and water on the surface of our globe, the configuration of continents, and the elevation of mountain chains, are the result of the uniform laws of nature? It is the action of these laws —the first and simplest of which is that of the action of gravitation— which we are now endeavoring to trace in the complicated results shown in the earth's surface features, but which results are as fixed and as certain and perhaps as capable of being traced back to their origin—the requisite time and patience being applied—as the figure of the most complex crystal may be shown to be derived under the action of fixed laws from one of the known simple primary solid figures. Let us again repeat Carl Ritter's words: "Although the present position of land and water seems fortuitous, undoubtedly it has a uniformly acting and thoroughly appreciable law."

Just as these pages are ready for the press, we observe in *Nature* of March 3, 1887, page 413, a communication from C. S. Middlemiss, dated Ramuagar, Terai, January 25th, 1887, on "Top-shaped Hailstones" which had just fallen near that place. But, besides the top-shaped hailstones, Mr. Middlemiss says: "In some few instances I found hailstones of another, but probably derived form. Instead of being circular in section at right angles to the long axis, they were triangular, so that they have a strong resemblance to the kernels of a beech nut. The broad end in this case was also perfectly transparent, and the sharper end banded as before."

This is clearly the same form as that of the hailstones referred to above in the Transactions of the Paris Academy of Sciences; "a solid of revolution from a spherical pyramid." The spherical drops of rain freeze on the outside first, and the expansion of the ice-crust compared with the internal water, produces momentarily, an envelope too large to embrace exactly its contained liquid nucleus. The ice-crust therefore accomodates itself to the now relatively diminished interior, by collapsing in that form which most quickly disposes of the excess of its linear dimensions. The force of compression would, in this case, be the pressure of the atmosphere, as a vacuum would

tend to form between the internal sphere of water,—or spheroid if in rotation—and the ice-crust too large for it. Possibly the fact referred to by Mr. Middlemiss that "the pointed end was banded crossing by alternate layers of clear and white ice" may be accounted for, inasmuch as the tetrahedral compression *produces* the pointed end, and the bands of white ice may be rifts or cracks, the result of that compression, or of the subsequent expansion of the nucleus when it froze.

APPENDIX TO CHAPTER II, PAGE 12.

On some objections which have been urged against the hypothesis of the earth's contraction and collapse by loss of heat as an explanation of its surface features.

The Rev. O. Fisher, in his work on the "Physics of the Earth's Crust," (London, 1881,) shows that the amount of contraction and cooling of a solid earth is incapable of accounting for the irregularities of the surface. But may we not ask, is there any single grand fact in the earth's phisiography which the hypothesis of a solid earth makes intelligible?

Mr. Fisher further questions whether the amount of cooling exhibited by the earth's crust, assuming it to rest on a molten substratum, would be sufficient to account for the bendings and the corrugations shown in it. One of the assumed conditions which he postulates—following Sir William Thomson is, that the whole molten nucleus, or substratum had arrived at nearly the freezing temperature by convection when the solid crust began to form. If the density of the substratum increases with the depth this cannot have been the case, as the assumed convection currents would not have acted, and there would have been a reserve of heat in the substratum or nucleus which may have escaped by various methods, and which loss of heat may make up the amount of loss of volume, which the estimates from the extent of the corrugation of the crust seems to require for their production.

If we consider what has been going on at Kilauea and Mauna Loa, during the last fifty years, and endeavor to make some estimate of the annual average amount of heat lost at these volcanoes and in their fissures, it cannot, we think, be made to come out much less than the total theoretical heat usually estimated as lost annually over the whole globe by simple conduction. The constant cooling, heating up again, and remelting going on in the lava lakes in Kilauea, indicate an immense loss of heat. Or, taken from another point of view, and independent of the continual loss of heat by radiation at Kilauea, and in the summit crater of Mokuaweoweo, fully a cubic mile of lava has flowed over the surface during the last fifty years. which has cooled from a temperature of say 2,000° F., to 3,000° F., to the temperature of the atmosphere. But this same loss of heat has been going on, according to all appearances, for thousands of years. The immense mass of cooled basalt—cooled from a white heat—exhibited by the Hawaiian

volcanic chain alone, points directly to a great and comparatively sudden loss of internal heat and volume during recent geological epochs.

When we consider the effects of all the volcano and fissure eruptions of the earth during past ages, it would seem that the loss of heat by simple conduction through the crust, may be insignificant in comparison. J. R. Mayer has called attention to the insufficiency of simple conduction through the crust of the earth as the means by which it loses its internal heat, but a study of Hawaiian volcanoes lends wonderful force to the following sentence:

"And we have not only to consider here, actual eruptions which take place in succession or simultaneously at different parts of the earth's surface, but also volcanoes in a quiescent state, which continually radiate large quantities of heat abstracted from the interior of the globe. If we compare the earth to an animal body, we may regard each volcano as a place where the epidermis has been torn off, leaving the interior exposed, and thus opening a door for the escape of heat."

Captain C. E. Dutton has brought forward a number of considerations which he considers to militate against the hypothesis that the formation of mountains is mainly the result of the collapse of the earth's crust on to the cooling and shrinking interior. (See *Penn. Monthly*, May and June, 1876, "Critical Observations on Theories of the Earth's Physical Evolution.") He takes, in part, the same ground that the Reverend Osmond Fisher does, and points out, that in view of the small depth to which physicists tell us the cooling has extended, the amount of possible contraction could not account for the observed amount of corrugation of the crust. This conclusion Captain Dutton arrived at quite independently of the Rev. O. Fisher's calculations.

But if the interior of the earth, being in a liquid state, may have lost heat to a vastly greater extent, by convection currents, by the exposure of that interior to radiation, "where the epidermis has been torn off," by constant enormous outpours of white-hot molten rock, and the injection of the same intensely hot matter into fissures and between the strata of comparatively cold rocks; it would seem that the amount of contraction due to cooling may be impossible to estimate, or how far down the cooling may have extended. Nor does it seem to be any serious objection to the theory, in the present state of our knowledge of the contraction hypothesis, if, as both these writers show, there are probably a number of other conditions besides loss of heat, in and under the earth's crust, which add to the effects of contraction, collapse and corrugation. For instance, the Rev. O. Fisher suggests the escape of the vapor of water, and other gases from the interior of the earth, although he finds that this alone would not produce the observed effects. Captain Dutton calls attention to the expansion constantly taking place in the cooled crust by metamorphism.

To the oxidation, hydration and constant chemical union of the elements of the solid rocks and the elements of the atmosphere, and which must of necessity decrease their specific gravity or cause the solid crust to occupy more space than it did before, in other words expand. We have taken the ground throughout, that this is necessarily a continued process, and that the time will come, as many physicists have suggested, when the whole atmosphere and ocean will be locked up, in the solid surface rocks—a process of expansion for these. The expansion of the crust would result in crumplings analogous to those caused by the contraction of the nucleus, as both Capt. Dutton and the Rev. O. Fisher have pointed out.

It would appear therefore, that the geologist may be sound in appealing to contraction and collapse, as the main dynamical basis of his science, leaving it an open question for the present, as to how much may be due to simple conduction of heat, how much to convection and exposure of the interior molten matter to radiation, how much to injection into the crust, and extravasation of the hot liquid over the surface of the earth, and how much, if any, to loss of volume by the escape of vapors, whilst the expansion of the crust at the same time, although not in a literal sense, part of the hypothesis of internal contraction, adds to its effect, and supplements it, if internal contraction alone should be considered insufficient to account for the observed amount of the collapse and corrugation.

There is one effect however, referred to by Captain Dutton, which he seems to consider to be inconsistent with the general principle, namely, that the masses of crust under the tangential pressure, would be acted upon by forces so great that their coherence would be a vanishing quantity. "Such masses, under the action of the supposed force, would be the merest rubble, and quite incapable of preserving their integrity."

But the reply which may be made to Mr. Mallet's hypothesis of the melting of rocks by the action of these enormous forces answer both. It is the very want of coherence, the impossibility of any masses of such comparatively yielding rock, ever being able to receive and transmit such enormous strains, which usually prevents our seeing the excessively violent results which such forces, when called into play, would otherwise be capable of affecting. As the strain is applied, the rocks give way by bending, and relieve it; so that as Lyell long since observed, the effects which we usually do see in the strata of the earth's crust, are more like those which we may suppose had acted "in the opening petals of a flower." (Lyell's Address to the Geological Society, 1850.) The rocks are always ready to yield, and there is little opportunity either for crushing the strata into dust or rubble, or for melting them, by sudden and violent movement, although now and then they seem to be rudely crushed. Where are the iron and steel frames, dies and followers in the earth's crust, answering to those in

Mallet's experiments in crushing rocks? Even then he could not melt them.

This, however, does not invalidate the principle to which we have appealed, of sudden effects being often produced, due to a constant or gradually increasing strain. The crust must have some resisting power, but this is in all cases, far within the forces which would be brought to bear, as the liquid columns lowered, if the crust had more resisting power. A common misapprehension seems also to arise here. The liquid interior seems to be often assumed to be either just supporting the crust or as having just left it wholly unsupported. This latter is probably an impossible condition of affairs when considering any large area of crust. If we bear in mind the principle of the floating crust of the earth being supported by colmns of liquid which may rise or fall gradually, we have a machinery which we can easily conceive capable of withdrawing the liquid support from the earth's crust in an almost insensible manner, but always leaving some support, and on which a small subsidence of the crust might again make sufficient to sustain it. It seems impossible that the enormous tangential forces, theoretically possible, should ever be brought into action.

We would here suggest that Captain Dutton's assumption, in the paper already quoted, p. 373, that the "contraction hypothesis," as presented by either Mallet or Fisher, is the best or the true representation of the theory, may not be correct, but that Beaumont's is the nearest approximation to a true conception of the principles involved, and their probable effects, although unfortunately, his complete views on these points are much scattered, though his "Notice sur les Systemes de Montagnes," and are illustrated by an hypothesis, as to the particular form of the earth's collapse, which is untenable.

With regard to the objection which both Capt. Dutton and the Rev. O. Fisher have referred to, namely, that the corrugation of the earth's crust by the contraction of the nucleus, should show equally all over it, if the earth be a true spheroid of revolution, we may remark, that the whole hypothesis of the tetrahedrai collapse rests upon the supposition—first suggested by Beaumont—that a slight change of figure of the whole spheroidal crust, might be the first effect of the contraction of the nucleus and might precede corrugation, as explained in Chapter II. The moment that this change of figure occurred, the effects on the crust of contraction and collapse, or upheaval and corrugation, would tend to be localized. The earth would no longer be an exact contracting spheroid. It is the localities where the depressions and the resulting upheavals and corrugations have mainly taken place, and to-day show themselves on the earth's surface, which lead to the tetrahedral hypothesis, and for which there now appears a geometrical reason.

The particular form of the contractional hypothesis which Captain Dutton seems to contemplate, and occupies himself in refuting—and

we think successfully—is that "the origin of continents has been attributed to inequalities in the conductivity of different parts of the crust; the conductivity of the land areas being supposed to be less than that of oceanic areas. Hence the escape of heat and the consequent contraction and subsidence would be less beneath the land than beneath the ocean."

Elie de Beaumont however, did not suggest or contemplate anything of this kind in his theory of secular refrigeration. Neither do we do so in the hypothesis of the tetrahedral collapse; but we have followed Beaumont in regarding the grander inequalities (bossellements generaux) of the earth's surface as due to a change of figure arising from the first slight tangential thrusts in the crust resulting from the partial withdrawal of its support,—the fluid columns lowering—and previous to crushing.

We can only understand the hypothesis of unequal conductivity, when applied to a solid earth, which we have thrown out of consideration, as explaining nothing intelligibly either with respect to the primordial deformation of the spheroid, or the subsequent fracture, faulting, corrugation and lateral movements of the crust, or, the universal injection of fissures by molten rock, or its almost equally universal outpour over the surface.

When we consider the broad facts of volcanic and igneous phenomena in the past, and the resulting loss of heat, the dykes and intercalated sheets of dolerite and basalt, the overflows from the same dykes that have now disappeared, the lava floods which still exist, the universal flood of basalt over the ocean bed, the deposits of basic pumice and red clay over these, and add to all the radiation and conduction of heat from craters and chasms which leave no record, it must be evident that the calculated loss of heat and of volume by simple conduction through the crust has been insignificant in comparison.

APPENDIX TO CHAPTER II, PAGE 27.

J. D. Dana on the Evolution of the Earth's Fundamental Features—("Manual of Geology," by James D. Dana, New York, 1880, page 826).

The concluding section of Professor Dana's "Manual of Geology," bearing the above heading, may be referred to as corroborating the main principles, appealed to in the hypothesis of the tetrahedral collapse. For example:

"The making of mountains involves the making of the earth's fundamental features."

"The positions of the great mountain chains along the borders of the continents, and of uplifts, fractures, plications, volcanoes, metamorphism, chiefly on the seaward slope of the mountain chains, prove that, while the force from contraction was a universal force over the sphere, the lateral pressure was vastly more effective in a direction from the ocean." * * *

"The different eras of mountain-making were mountain-making eras for all the continents alike; 'the mountain ranges in their respective positions on each side of each continent' have been alike in general direction, indicating that the all-pervading force was in each place at its old work through all the successive ages." * * *

"The force has thus acted as if one in origin and nature, and has manifested at all times the fact that one single system of evolution was in progress."

All that the tetrahedral hypothesis proposes to add to this is, that these ocean depressions were simple subsidences resulting from the necessity of a change of figure of the earth in order to accommodate the difference between the dimensions of the hardened crust and the contracting interior. That these great subsidences were four in number, forming the Arctic, Atlantic, Pacific and Indian Oceans, three of which subsidences (the Pacific, Indian and Atlantic) Professor Dana calls special attention to, and well illustrates in the last chapter of his work on "Corals and Coral Islands," New York, 1874, under the head of "The Oceanic Coral Island Subsidence." The tetrahedral hypothesis assumes that the centers of these four subsidences were originally situated at four equi-distant points of the spheroid, one being at the North Pole, and therefore symmetrically placed with reference to the earth's axis of rotation, tending to produce a geometrically regular collapse.

Where we depart from Professor Dana's views is, as to the cause of the subsidence of the ocean beds, which, however, is not referred to by him in the chapter from which we have just quoted, but in an article in the *American Journal of Science*, Vol. 5, page 423, on "Results of the Earth's Contraction," Professor Dana explains that he looks upon these ocean subsidences as the result of "unequal radial contraction," and that (page 424) the oceanic areas were the subsiding areas, "that is those which contracted most." We do not see the necessity for this somewhat arbitrary hypothesis, but conceive that the first strains of compression on the thin crust, as it collapsed on to the uniformly contracting nucleus, would produce a slight general deformation of the spheroidal crust, exhibited by four grand depressions and four corresponding, but antipodal, prominences.

But now, further, Professor Dana has to notice an irregularity, thus:

"*The System of Trends.*—While the relative positions of the continental plateaus and oceanic basins have influenced the general direction of the action of lateral pressure, some unexplained cause—perhaps the existence of a cleavage structure in the crust, or at least the existence of directions of weakest cohesion, in part controlled the courses of fractures and uplifts, somewhat as the warp and woof in a piece of cloth, fix the courses of rents, while the direction of the force applied determined the positions and extent of the rents." ("Manual of Geology," page 827).

Professor Dana then attempts to explain how the unequal action of the pressure from the subsiding ocean beds, and oblique to the assumed structure courses, might produce the bends or great curved lines which the tetrahedral hypothesis attributes to the effect of the rotation of the earth on the collapsed areas in middle latitudes, and to the two sets of great astronomical fractures—polar circle and ecliptic—due to the internal tidal distortion. The "unexplained cause," and the "warp and woof" Dana was looking for.

But Professor Dana seems to distrust the principles on which he had so far proceeded, for he says (page 828):

"Why the continents are gathered about the North Pole, and the waters about the South science does not explain." But a little further on he adds:

Further, astronomy does not allow geology to conclude that the prevalence of water about the South Pole is sure evidence of less or lower land than at the North,—teaching that if the earth's mass has greater density there it would have more water through its attraction."

It would have been satisfactory if Professor Dana had shortly explained, how and why, astronomy does not allow geology to conclude that the prevalence of water about the South Pole, may be simply the result of the subsidence of the three ocean beds, mainly in the southern hemisphere; which with the fourth area of subsidence at the North Pole, at once accounts on this hypothesis, for the position and general configuration of all the continents and oceans of the globe. Astronomy can hardly object to a symmetrical figure of this character.

In the conclusion of this section (page 831), Professor Dana observes: "It (Geology) gives no cause for the arrangement of the continents together in one hemisphere."

That is, for the land and water hemispheres; but Professor Dana appears to leave this phenomenon amongst those, which he refers to shortly afterwards, as "the spiritual element in geological history, for which attraction, water and fire have no explanation.

It seems remarkable that Professor Dana having just suggested a mechanical cause for the prevalence of ocean in one hemisphere, should desire to propose an entirely distinct class of causes, for the prevalence of land in another.

The land and water hemispheres, may follow—as explained in Chapter II.—in regular order as a mechanical result in the theory of the tetrahedral collapse. Even our best leaders in science, seem desirous of fixing the boundary of the operation of natural causes, by the limits of the knowledge or the discoveries of the hour. The scientific world owes Prof. Dana a large debt for his contributions to geological science, and in no branch more, than for his bold and valuable teachings in geographical evolution. Leader and chief, though he be, in these branches of knowledge, why should he now, sit on his throne at

the edge of the advancing tide of physiographic research, and say, thus far shalt thou come and no farther.

APPENDIX TO CHAPTER III, PAGE 38.

Reply to a Notice and Query by E. H., in the *Geological Magazine*, July, 1882, page 327.

In a short notice in the above *Magazine* of M. De Lapparent's paper in the "Revue des Questions Scientifiques" for January, 1882, entitled "La Symetrie sur le Globe Terrestre," E. H. asks "What does he mean by saying that conjunctions of the sun and moon are most frequent at the solstices?"

M. De Lapparent was mainly explaining our views in that paper, and we are responsible for the following statement in the first part of the *Vestiges of the Molten Globe*, page 36:

"The solstices are the periods when the rupturing effect in one direction has the longest time to act, and when also there would be a greater number of conjunctions and oppositions." This was further explained by the following note:

"The sun remains a longer time nearly vertical to latitude 23° 28′ N. and S. than to any other latitude. There have occurred, therefore, more conjunctions and more oppositions of sun and moon, when the sun is nearly vertical to 23° 28′ than when it is nearly vertical to any other latitude—that is, near the solstices. The sun remains nearly half the year vertical within seven degrees of one tropical line or the other, whilst in the other half its verticality ranges over 32° of latitude."

It is therefore true that, viewing the solstices as periods when the angle made by a plane at right angles to the earth's orbit and to the radius vector, remains in one definite position, relative to the earth's axis of rotation—which indeed is the meaning of the term—there would be a greater number of conjunctions and oppositions of sun and moon at the solstices than at any period of the year, when the sun is more or less rapidly increasing or diminishing its altitude. In fine, "the solstices are the periods when the rupturing effect in one direction has the longest time to act;" or, as we explain in chapter 3 of the present volume, with respect to the special question at issue—the angle made on the earth's surface by a plane at right angles to the plane of the ecliptic and to the radius vector—the solstices are the only periods of the year which can be said to have any duration whatever, for at any other time that angle is constantly changing.

How has E. H., in this short notice, so far misunderstood M. Lapparent's clear explanation of the assumed tetrahedral collapse and the earth's figure, as to state that "the form is to be more strictly that arising by development of pyramids on the original four faces; *thus are explained South America, Africa, Australia and Greenland.*" The italics are ours. Nothing to this effect is to be found in Mons. De Lapparent's paper, nor in our book.

APPENDIX TO CHAPTER III, PAGE 51.

On Mr. G. H. Darwin's hypothesis of the distortion of the earth's surface features by the rotation—retarding attraction of the moon. The Rev. O. Fisher and Mr. W. B. Taylor on the crumpling of the earth's crust in connection with the diminishing velocity of its rotation. The rotation of the earth and moon, tidal friction and tip of both their axis resulting from change of figure.

Mr. G. H. Darwin's mathematical speculations on the effects of tidal friction in reducing the velocity of the earth's rotation and increasing the orbital distance of the moon, answer very well, as far as they go, to intensify the effects in early times, which we have attributed to the action of the internal tide wave and to that of the earth's rotation on subsiding and upheaving areas of the crust respectively, and which effects, judging from the probable extent of the present internal luni-solar tides, and the present velocity of the earth's rotation, as well as the probable present rate of loss of internal heat, might be considered to require a former more powerful, or a more rapidly acting moving cause.

Mr. G. H. Darwin refers the twisting effect so evidently exhibited in the earth's surface features—and which we have ascribed to subsidence and the earth's rotation—to the retarding attraction of the moon acting more powerfully, as the earth rotated, on the equatorial regions. The crumpling and fracturing also, of the earth's crust, he attributes largely to the same cause, but estimates that the effect, during the later geological ages, say during the last 45,000,000 years, has probably been insignificant.

But Prof. A. Geike has pointed out (Text Book of Geology, London, 1882, page 285,) that the vast elevation of the Andes, for instance, must be referred to a comparatively recent geological period and not to events which happened so long as 45,000,000 years ago.

The simple subsidence therefore, of the bed of the South Pacific seems to be a more probable cause for both the elevation of the Andes and the eastwardly thrust of South America; for granting the subsidence, the tendency of the eastward rotation on the subsiding bed to push it to the eastward, must also be granted. The same effect is exhibited in the other two southern oceans.

The tendency towards the same effect, due to the moon's retarding attraction, as suggested by Mr. G. H. Darwin, especially in early periods, may well be added to that of rotation on an upheaved and subsiding crust, but it will hardly take the place of these. Mr. G. H. Darwin's hypothesis stands by itself, in attempting to account mechanically for one of the most prominent of the earth's surface features. In our hypothesis however, this twisting effect on the earth's crust appears as part of a system which may be termed the tetrahedral deformation of the rotating spheroid, resulting from loss of internal heat. The position and forms of all the continents and oceans together, are explained in that simple postulate, whilst the twist or the irregularity

displayed in this geometrical deformation, is shown to be a mechanical result, to be expected from that particular collapse, under the influence of the earth's rotation, This hypothesis explains at the same moment why there is an Arctic ocean and an Antarctic continent, why there are three oceans mainly developed in the southern hemisphere, why there are six half-continents divided by inter-continental seas with the apices of the southern continents pointing into the southern oceans, and finally why five of these half-continents are crowded together in one-half of the globe, leaving Australia with its kangaroos out by itself in the water hemisphere.

Mr. W. B. Taylor, in a paper read before the Philosophical Society of Washington, on the "Crumpling of the Earth's Crust," and published in full in the *American Journal of Science*, of October, 1885, page 249, places in a very clear light the importance of considering another crumpling effect which the diminution of the velocity of the earth's rotation may have produced—nay must have produced—on the earth's surface, for the change of figure which must have accompanied a diminished rate of rotation, and the approximation towards a sphere, necessarily leaves any solid crust which may have formed on the more flattened spheroid, too large for the new figure, and this effect might be expected, as the Rev. O. Fisher had previously pointed out (Physics of the Earth's Crust, page 183,) to be exhibited in the corrugation of the crust, specially in equatorial regions. Not being able however, to point very definitely to this result in these regions, the Rev. O. Fisher suggested (page 184) that the effect might have become obscured at the equator, from the circumstance that the "latitudes of places on the earth's surface are liable to change." Mr. Taylor however, suggests with apparently good reason—that the internal luni-solar tide-wave—the crests of which stand, as the earth rotates, in a plane closely tangent to the two tropical lines, during a large part of the year—may well have modified the location of these corrugations and have caused them to appear nearer to the two tropical lines than to the equator.

Mr. Taylor further remarks with reference to Mr. G. H. Darwin's speculations on the crumpling of the earth's crust, in connection with the diminution of the rotational velocity, that "the striking significance of this physiographic generalization," (that is the crumpling due to change of figure by lessened rotation,) "appears to be strangely overlooked." (Page 262.) In these speculations we should do well to bear in mind Charles Darwin's caution already quoted, (Chap. II. p. 25,) in connection with the hypothesis of the earth's contraction and collapse by loss of heat, that "there must be many agents modifying all such primary powers," whilst we see how easy it is for those mathematicians even, whose attention is concentrated upon this very theory, to miss results or effects which are obvious when pointed out. We ought not therefore—if satisfied that the general theory is correct—to give up looking for definite physiographic results, because they

do not at once appear precisely where and in the manner we expect to find them.

May we venture again to suggest, however, to those physicists and mathematicians who have this rotation-retarding problem under consideration—and this applies both to Mr. Darwin's and Mr. Taylor's theories—that so far as its effects may be looked for in the earth's surface features, we should bear in mind Prof. Geike's caution, that earth-crust corrugation is not only an effect referable to times and conditions long past, but is one that has been in action up to geologically recent epochs, that in fine, mountain making, as Charles Darwin and others have shown, is a process still in operation. It will hardly be contended that the rate of retardation of the earth's rotational velocity to-day can have any appreciable effect in such phenomena as the sudden lifting of the coast of Chile and the Chilean Cordillera, in 1835. The diminution of bulk and the extravasation over the surface of the crust, of the molten nucleus, still proceeds however, and, as we endeavor to show in the text, to an extent that may probably produce those great physiographic catastrophes which every now and then astonish the world.

We would further suggest that the initial—and may we not say continuous—tetrahedral collapse, must have largely controlled or modified the position and direction of the earlier corrugations that may have been due to the diminishing ellipticity of the planet, with the lessening velocity of rotation in early times, if such were really produced, and as we have indicated throughout, the great lateral shift of the crust along the zone of fracture parallel to the plane of the ecliptic—or in the plane of the movement of the crest of the luni-solar internal tide—would have modified the position and direction of the crumplings *due to all the other causes combined.* If it were not for the fact that in all these irregularities of the earth's surface features we still perceive the clearest evidence of a pervading symmetry, and that even the irregularities appear amenable to rule and law, we might well despair that our efforts to refer such complicated features to their true causes would be successful. We have every reason to hope, however, for valuable results in this direction.

If we have properly understood these planetary rotation problems with the tidal distortion and tidal friction of a viscous spheroid, the following questions suggest themselves.

Is it correct to assume that the present apparent time of rotation of the moon—once in a revolution—is the result of tidal friction alone? Are not the chances, as Laplace pointed out, vastly against the probability of such a cause alone, reducing the time of rotation to exact accordance with its period of revolution? But is it not, as Laplace also suggested, that this accordance is mainly the result of the attraction of the earth on the prolate hemisphere of the moon which is now turned towards us, and held there, exactly, as Laplace also observes, as a vibrating pendulum (subject to friction understood).

is brought to the vertical? If this be the case, it does not seem correct to consider this apparent rotation of the moon as a true mechanical rotation on its axis, for, as we have observed in Part I., the moon, having this prolate figure, the axis around which it appears to rotate, cannot be a principal axis, but around which principal axis it must rotate, if free from the attraction of the earth, or other external body, on its prolate face:

This distinction between an apparent rotation on *an* axis, and a real mechanical rotation on a principal axis, seems important, for it would follow that the direction in which the moon now appears to rotate, may be different from the direction in which it actually did rotate, before the attraction of the earth on its now prolate side, forced that face of the moon to point constantly towards us; and different to that direction, in or towards which it would instantly commence to rotate if freed from such external attraction.

There have been warm discussions at different times during the last fifty years about the rotation of the moon on its axis, and those who have doubted this proposition, have generally been put down by some physicist or astronomer, but with arguments that seem unsatisfactory. On the other hand, the objectors have not perhaps, properly stated their case. They should have admitted the apparent rotation, but shown that it was not a rotation on a principal axis, that is, not a free and true mechanical rotation.

Mr. Proctor admits (The Moon, London, 1873, page 170,) that "if the body be not spherical, forces tending to produce a rotation come into play," but he considers that in the case of the moon "such forces are altogether too small to produce any appreciable amount of rotation during a single revolution." We should not venture to question this view of an able astronomer, did we not seem to have Laplace in our favor. Mr. Proctor has elsewhere likened the moon's figure to "a rounded egg," with the small end pointing towards the earth. This is just the condition required. Have astronomers decided how much the small end of the egg projects, and what time would be necessary *in earlier times*, for the attraction of the earth—in concert with lunar-tidal friction—to force the pointed end to keep itself constantly turned towards the earth? Let us call this movement when consummated, rotation if we choose, but let us keep such a rotation separate, in our minds, from the rotation which the moon—assuming a sufficiently prolate figure—would necessarily acquire very shortly after being freed from the attraction of the earth on its prolate side, and which rotation could not then continue with its axis at right angles to the prolate axis.

If most of the satellites—as it has been often suggested may be the case—always keep one side turned to their primaries, the chances seem enormous against the view, that this exact accordance between the rate of rotation and the annual revolution, could have been produced by tidal friction alone, as Laplace long ago suggested; but it

may well be the result of the attraction of the primary on the distorted spherical figure of the satellite, which acting in conjunction with tidal friction in its interior, or exterior, or both, must ultimately bring the projecting side to point to its primary just as gravitation and friction bring a swinging pendulum to the vertical.

This view of our satellite's figure and pseudo-rotation on an axis would have—if true—a most important bearing on the theory that the inclination of the earth's axis of rotation is mainly due to the attraction of the sun and moon on the earth's tetrahedral prominences in the northern hemisphere.

APPENDIX TO CHAPTER III, PAGE 53.

On the change of inclination and of the position of the earth's axis due to a change of figure.

There has been a great deal written of late respecting the changes which may or may not take place in the earth's axis of rotation by changes of level on the earth's surface, and as the subject may involve the question of climate in former geological periods, it is one of great interest.

Several writers have treated the question mathematically, and by assuming a solid earth have calculated that large geological changes could only produce a small change in the position of the axis of rotation. On the other hand, Sir William Thompson and others have explained that whilst the earth may have been in a liquid or plastic state, almost any amount of change may have taken place in the position of the earth's axis of rotation, but not in its inclination. But, says Sir William Thomson, the earth is now, and has been for ages, virtually solid, or at least so rigid, that this kind of change in the earth's axis of rotation cannot well have occurred in the known geological epochs. (See *Nature*, November 5, 1874, page 345. Abstract of Sir William Thomson's address at the Geological Society of Glasgow, on "The Influence of Geological Changes on the Earth's Rotation.")

As far as results are concerned, we arrive at the same conclusion that most of the mathematicians do, namely, that during the recognized geological periods no material change has taken place either in the position of the earth's axis of rotation, or in its inclination to the plane of the ecliptic.

But we arrive at this result from the consideration of an entirely distinct set of phenomena, and on opposite grounds. We take the earth's surface features, including volcanoes, and we deduce from their study a globe with a molten interior and a thin crust. We find this crust to have been notched, ages ago, in the most distinct manner by lines which must have been formed when the axis of the earth's rotation bore substantially the same angle to the plane of the ecliptic that it does to-day. Thus, the permanence of the angle of the inclination of the earth's axis of rotation becomes to this extent an

observed fact, and one which the internal tidal action of the sun and moon has registered on its surface.

But if the inclination of the axis of rotation to the plane of the ecliptic has for ages remained permanent, the position also of the axis of rotation cannot well have changed, for it is hardly probable that the earth should have materially changed the position of its principal axis, which has afterwards inclined so as again to coincide with the inclination which its former axis had. Further, a consideration of the same surface features indicates that the grand changes of level in the crust of the earth are based on a regular mathematical figure, such that they must, however extensive, have always been approximately symmetrical with the earth's axis of rotation. A tetrahedral collapse, or a tetrahedral oscillation of the earth's crust, one axis of which is the axis of rotation, would not alter the position of that axis on the earth's surface a single inch, so long as the four areas of subsidence and the four areas of upheaval, oscillated in unison, and which general uniform oscillation in corresponding areas is part of the hypothesis, as well as being a doctrine taught by geology. As a matter of fact, mountain ranges in the different parts of the world seem to have been upheaved simultaneously in each geological epoch. There is no reason why such symmetrical depressions and upheavals should change the position of the earth's axis of rotation; and still less reason, having once acquired the general tetrahedroidal figure, and having responded to it by inclining—not changing—its axis of rotation, till it assumed a position of comparative repose between the attractions of the sun and moon, why the earth should again change either the position or the inclination of its axis, even with great, but symmetrical, oscillations of the tetrahedroidal crust.

We should not omit to bear in mind, however, the possibility of small changes both in the latitude and longitude of certain parts of the earth's crust by the sliding of the shell over the fluid or plastic substratum, as Mr. Prestwich has often suggested. This might be accompanied by a slight movement of the position of the axis of rotation. The sliding itself, however, would be, to a certain extent, governed by the position of the axis of rotation; that is to say, the masses so sliding would tend to move into a position conformable to it. There would, perhaps, be, to some extent, a mutual accommodation between a change of axis and the sliding of the shell, as the Rev. O. Fisher has remarked.

APPENDIX TO CHAPTER IV., PAGE 94.

On the elements contained in Olivine-Basalt and the changes that take place in it. Professor J. W. Judd on Gabbros Dolerites and Basalts.

Exception has sometimes been taken to the term Olivine-Basalt, on the ground that all basalts contain olivine. We adopt it, however, because a basalt with a large proportion of olivine seems to be the pri-

mary magma of oceanic volcanoes, and that it is an accident when this mineral is not abundant in it. There seems indeed to be some ground for making a distinction between olivine-basalt and basalt containing a considerable portion of augite, for when there is much olivine there is often little or no augite. Lyell refers to this description of lava as constituting the higher portion of the Island of Madeira, and says (*Manual of Geology*, fifth edition, page 521), "M. Delesse, after examining my specimens, informs me that in France they would call this rock *basalt*, although it is often without augite, and simply a mixture of blackish-green feldspar with olivine." This description would seem to answer for a large portion of the lavas of the Hawaiian group, and perhaps of the oceanic volcanic islands generally.

The lower outflows on Hawaii are sometimes nearly all olivine. Dana has suggested that the original olivine may sometimes go to form augite, that is augite may often be, before eruption, secondary to olivine, whilst Daubree's remarks upon it as the universal scoria, give it great importance. Again, the large number of the heavy metals in olivine is remarkable. Nickel, tin, copper, iron, chromium, manganese, zinc and lead, have all been observed in it. Daubree shows that platinum is often found in connection with it. The principal deposits of manganese, chrome and nickel, are usually found in connection with strata of serpentinous rocks which are generally considered to be the result of the alteration of olivine, indicating, along with other facts, that these metalliferous lodes and beds may be segregations, under the decomposing influences of hot water, of minute quantities of metals extracted from the irruptive or eruptive rocks. If this be correct these ore deposits, rich in the heavy metals, indicate the enormous mass of basic rocks which have been acted upon, but which have often themselves disappeared. Even the precious metals gold and silver, are believed by some observers to be often segregated in veins or lodes by the percolation of vast quantities of heated chemified waters through masses of basic irruptive rocks which contain them in extremely minute—almost insensible—proportions (see G. F. Becker's Report on the Decomposition of the Comstock Rock Masses). It will be unnecessary to remind geologists that the main elements found in the earth's crust exist in it and in basalt in somewhat the same proportions, say oxygen with silicium, aluminium, calcium, magnesium, sodium, potassium, iron and manganese.

The writer has suggested in a paper read before the Royal Geological Society of Ireland, June 14, 1876 (see their Journal, Vol. IV., Part 3), that many marbles (especially the verde antique) and magnesian limestones may derive some of their peculiar characters from the very fine olivine sand which became segregated by the ordinary degrading and sorting action of the ocean waters, and which became subsequently metamorphosed, and that even the filling of the pores of Eozoon Cana-

dense (whatever that may be) may have been originally fine olivine sand, derived from the disintegration of olivine-basalt, and as the fabric of Eozoön itself, as well as coral rock, is probably formed from the lime extracted by the carbonic acid of the atmosphere from basic igneous rocks and carried into the ocean, we can thus trace the metamorphosis of the original cosmical magma olivine-basalt—not only to silicated crystalline schists, and to granite on the one hand, but to the limestones dolomites and marbles on the other, which contain just the elements of the basalt, of which the former are more or less deprived.

Olivine-basalt and the atmosphere seem to contain nearly all the main elements of all the main rocks and rock forming minerals, except sulphur, which we elsewhere suggest (see Appendix, p. 254,) may be a compound manufactured from the elements of the atmosphere and water in the alembic of a volcanic orifice, and the origin of which, considered as an easily vaporizable element existing in the heated bowels of the earth, has always been a puzzle to both chemists and geologists.

We cannot do better here than call attention to some very condensed and practical, at the same time eloquent, remarks of a mineralogist, on the changes which minerals and rocks must and do undergo by ordinary as well as extraordinary atmospheric action. We quote from the *Mineralogical Magazine*, Vol. III, No. 14, page 28 and on, being a notice of a paper read before the Royal Society of Edinburgh, April 1st, 1878, on "Augite, Hornblende and Serpentinous change;" by Prof. M. Forster-Heddle. We have taken the liberty of emphasizing in italics what we deem specially favorable to the general view suggested in the text, of the derivation of most minerals and rocks from olivine-basalt by atmospheric action.

(Page 133.) "The leading summary of our kowledge may be stated thus:—The primary agent of change is meteoric water, holding carbonic acid and oxygen in solution."

"The secondary agent is spring water, holding less oxygen, more carbonic acid, and certain salts in solution. The third agent is these same waters, sinking downward or rising upward, but now holding more complex salts—the products of the first operation of the waters themselves,—these salts being the agents of a second set, perhaps an endless cycle of changes, generally more potent than the originals.

"As regards the substances operated on, we know that those most easily attacked are carbonates and silicates of the alkalies, the waters thus becoming charged with most potent graving tools.

"Next we have *silicates which contain lime, protoxides of iron, and of manganese.*

"Lastly, we know that silicates of alumina and magnesia are the most stable of all; for carbonated water has no action upon silicate of alumina, and but a slight one on silicate of magnesia.

"In virtue of the above,—from compound silicates carbonated waters

will abstract the *silicates of lime, iron and manganese;* leaving the silicates of magnesia and alumina as residues.

"In virtue of the above,—the rock masses which we find in nature to be least prone to decomposition, are either immediately silicates of alumina and magnesia, or they are such as have originated from the alteration of the *less stable silicates.* Such are—steatite, talc, silicate of alumina, clay, kaolin, and sand itself—among simple silicates; and mica, chlorite serpentine, asbestos, and mountain leather—among compound ones.

"These, however subject they may be to mere complex changes induced by saline or alkaline waters, are no longer liable to further alteration through the *operation of atmospheric agents*—such as oxygen, carbonic acid, and water.

"Thus it is, then, that *serpentine asserts itself* wherever occurring; protruding as lines of rugged eminences, fitter types of the attributes assigned to the "everlasting hills" than the lordlier granitic masses around it; thus it is that the *mica crystal,* which torn from that granite, and mechanically comminuted but intrinsically unchanged, has served its purpose of giving continuity and sparkle to sandstone of newer and still newer epochs, *glitters, yet untarnished* mid the sands of the seashore; and thus it is that these *sands themselves,* buffeted by the waves of Cambrian and Old Red, and Coal Measures, and Permian, and it may be still more recent epochs, amid many surrounding changes have known none, but atomies though they be, seem quite large enough and hard enough again to complete a like extensive cycle.

"Thus it is that the *the clay which, as impure kaolin,* the rain-drop has gouged out of the feldspar of that granite which, soft as mud, gives way to everything, but can be changed by nothing, is seized upon by man to be fashioned into a structure harder, less compressible, more durable than stone itself.

"Thus, then, the mere passage of a current of carbonated water over minerals containing, or rock containing lime, iron and silica, is sufficient to sweep these substances in solution out of the rock, and to do so, moreover, with great rapidity."

"Hence the direct and unfailing action of such waters upon angitic rocks must be their conversion into serpentine."

"Again (page 142) it will be observed that both (augite and hornblende) occur together in the basalts and dykes of Elie and Kinkell; in these the one mineral—the augite—has undergone fusion, while the other—*the more fusible*—appears unchanged. This circumstance becomes a strong argument in favor of the latter having been formed *in situ—i.e.,* after the eruption and cooling of the containing rock—an ex-filtration product in fact."

In this paper we have succinctly placed before us the main changes which take place in the auhydrous and unstable minerals, olivine,

augite and labrador, and the final results which exhibit themselves in the minerals and rocks "no longer liable to further alteration through atmospheric agents"—the "untarnished" mica and talc, the self-asserting serpentine, the hard quartz and kaolin, which is fashioned into "a structure more durable than stone itself." In the same paper is shown in detail the changes which take place in the augites—their gradual loss of lime—and their passage towards hornblende; the main intermediary mineral in a general process of transmutation, but itself destined to extinction, whilst the quartz, orthoclase, kaolin, mica, talc and serpentine survive the accidents of their environment, and appear almost alone in the lowest and oldest formations, some of them being found chemically combined with the water which has been the main agent in their conversion from unstable to stable minerals.

It may be well to remark here that Bischof has called attention to the fact that olivine and magnesian mica, both containing a large proportion of silicate of magnesia, and both finely divisible into plates, and therefore liable to decomposition, are quite differently affected by acids; olivine being one of the most easily decomposed minerals, and mica the reverse. He says: (*Chemical and Physical Geology*, Chap. II, page 367) "If magnesia were in all instances a considerable constituent of mica, the great durability of this mineral might appear to be owing to the presence of silicate of magnesia, which is likewise present in the very durable minerals—chlorite, serpentine and steatite. But in potash-mica the amount of magnesia is so small that it cannot be supposed to contribute in any degree to the durability of the mica." Again: "The great durability of mica is accounted for by its composition only in so far *that it does not contain lime* as an essential constituent, but only in very trifling amount."

In fine, all these "metamorphic" and durable minerals appear as *the result* of atmospheric influences, and on that account are no longer subject to them, whilst all those minerals—the product of igneous fusion, and coming from the bowels of the earth, which are for the first time exposed to the atmosphere—be their composition what it may—are immediately attacked by it, and decomposed or transmuted until their elements become united under conditions which enable them to resist further change by ordinary atmospheric action. Many of the minerals, even, which are usually found in the more acid lavas—here assumed to be the result of the action of water, or aqueo-igneous fusion—such as sanadin and leucite, seem to be easily metamorphosed, and disappear in the oldest strata. It is not, then, the chemical composition of minerals which gives them stability *in the atmosphere* so much as their molecular condition produced by the decomposition and recomposition of their elements under atmospheric influence.

The loss of lime, however, which seems to be the rule in the general transmutation of rocks probably adds to the stability of many metamorphic minerals, as Bischof suggested in the case of mica.

The importance of olivine-basalt and the suitability of the term as a generic one, to signify the original magma from which all rocks have been derived, has been further impressed upon us since reading Prof. J. W. Judd's papers on the Tertiary and other peridotites of Scotland (Q. I. G. S. Vol. XLI, p. 354) and on the Gabbros, Dolerites and Basalts of Tertiary age in Scotland and Ireland (Q. I. G. S. Vol. XLII, p. 49). In these carefully written papers Prof. Judd shows how a large series of minerals and rocks, having names innumerable, may all be developments from what may once have been a structureless molten basic glass or tachylite, and which—having been kept at a great heat, and then cooled quickly—may not show under the microscope any minerals whatever. Then, as the cooling may occur more and more slowly, how it may become first microlitic, then a magma-basalt, then a basalt, then a dolerite, then a gabbro. Then how the simple subsidence (probably) of certain heavy minerals may eliminate them from the magma before it cools, thus giving rise to rocks which receive new names. Also how reactions may take place during the cooling when complicated with the subsidence of certain minerals, and by which new minerals may be formed independent of external agencies, giving rise to new species of rocks. Then, when external agents are called in—water, heat, pressure, mechanical strains, carbonic acid, oxygen, etc.—new minerals, new combinations and new rocks become abundant. What Prof. Judd calls Schillerization and other metamorphic processes, to which various names have been given, produce the series of changed olivines, changed augites, and changed feldspars, such as the varieties of bronzites, diallages and hypersthemes. Also the very large class of hornblendes, as well as chlorites, serpentines and hydrated minerals of various kinds, the feldspars being converted into Saussurite and into Zeolites. Finally appear the Micas and talcs—largely the result of compression—into which most of the already changed or derived minerals seem to be ultimately converted. That is to say, they pass through processes of change until all the possible or probable ones have been exhausted.

Going a little further than Prof. Judd takes us in the old Peridotites and Gabbros, may we not say, that nearly all minerals go through changes until they arrive at the comparatively stable forms of mica, talc, quartz, orthoclase and kaolin, as found in the granites, gneisses and schists, or at the equally stable form of serpentine which is the last term of change of the magnesian minerals, and especially of olivine.

Gabbros, dolerites and basalts, seem to be more or less differentiated forms of the highly basic lavas which now run over at different levels on eastern Hawaii, and which indeed form—also in a more less changed condition—the Hawaiian Group, and, may we not say, the whole of the oceanic, and the larger portion of all the volcanic ranges of the world, whether we call them gabbros, dolerites, basalts, andesites, porphyrites, diabases, melaphyres, propylites or diorites.

A structureless magma, of which the main potential minerals are olivine, basic feldspar and augite seems to underlie the earth's solid crust. These minerals are at the same time the main constituents of the stony materials which Mr. Proctor shows have probably been expelled during past ages from all the suns, and from all the planets when in a sun-like state. Olivine-basalt, or rather a molten glass which will cool to that rock, is the combination of elements which may claim the appellation of the cosmical rock, and which contains all those elements in the requisite proportions which in *conjunction with the atmosphere and water* will produce all the main rock-forming minerals of the globe.

APPENDIX TO CHAPTER IV, PAGE 103.

On Volcanic Sulphur, Sulphuretted Hydrogen, Nitrogen, and Carbonic Acid.

Sulphur and nitrogen have often been brought up on suspicion of not being elementary substances. With regard to sulphur, the consideration of its mode of appearance at volcanic vents leads also to the suspicion that it may be manufactured on the spot. It is admitted that it does not come up with the columns of molten lava. It is not a constituent part of lavas, nor of their primary minerals. Being so easily vaporizable, it could hardly exist in them. If we fall back upon the hypothesis that its appearance at volcanic vents arises from the decomposition by heat of beds of sulphur compounds, we have then to ask how the sulphur of those compounds arose? But it is incredible that the hot lavas of volcanoes can continue for ages to sublime fresh sulphur from the beds through which they pass—the supply would soon be exhausted; and yet volcanoes always and continually produce sulphur. It may be worth the attention of chemists to inquire whether, like nearly all the rest of the volcanic emanations, it is not a product of the elements of the air and water, which the hot molten lavas are constantly inhaling by downward convection currents, and then subjecting them to intense heat and pressure, and to, at least, decomposition. It seems always, or often, to appear in connection with the vapor of water. Can it be a hydrogen compound, formed from water, the oxygen of which has united under pressure in the hot molten lavas, with the iron and other metals, leaving the hydrogen free, and in the nascent state, to form the sulphur, or what is called sulphurretted hydrogen, which seems to be the usual conveyance for it towards the surface of the earth? But what may the other element be?

Nitrogen is a common product of volcanoes, and may be readily accounted for by the supposition that the hot lavas inhale air by violent downward convection currents, the oxygen of which combines with the white-hot iron and metals of the lava, forming, for instance, magnetite, leaving the nitrogen to escape alone. Has the nascent hydrogen from the water also decomposed by the lava, combined with

the nitrogen of the atmosphere under the influence of heat and pressure to form the stable compound sulphur—say hydrogen 2, nitrogen 14=sulphur 16?

Bischof says: "The existence of sulphur prior to organic life appears very doubtful." ("Chemical Geology," by Gustav Bischof, Clarenden Press, Vol. I, page 344.) May we not rather say, or also say, the existence of sulphur without volcanic action appears very doubtful.

Sterry Hunt, however, has observed that electricity always produces a sulphurous odor. Has electricity chemically united the hydrogen in the moisture of the atmosphere and the nitrogen belonging to it? Sulphur constantly appears where it is not expected, and often not wanted, in connection with intensely-heated substances.

It need not be fatal to such an hypothesis, if nitrogen itself should prove to be a compound also, and not an element. It suffices if it be a stable compound. It seems to be a gas which has had its affinity satisfied, or rather its inertness may arise from its being the result of the union of two active elements.

Mr. Henry Kilgour, of Edinburgh, considered that nitrogen was a stable form of carbonic oxide, their atomic weights being the same. Many circumstances conspire to excite this suspicion. (See *Mechanics' Magazine*, October and November, 1865).

Further, Mr. Hannay found in his diamond-making experiments that, in order to obtain the carbon in the required crystalline state, it is necessary that a stable compound containing nitrogen be present. (*Popular Science Review*, April, 1880).

Dr. J. F. Gilbert in his opening address at the Swansea meeting of the British Association in 1880, made this remark:

"In fact, assuming all the other necessary conditions to be provided, it was seen that the amount of carbon assimilated (by plants) depended on the available supply of nitrogen." (*Nature*, Sept. 23d, 1880, page 497.)

Liveing and Dewar found, in their experiments "On the Spectra of the compounds of Carbon with Hydrogen and Nitrogen," that the spectrum of the hydro-carbon bands was seen in a nitrogen atmosphere, but not otherwise. (*Nature*, Oct. 28, 1880, page 620.)

Nitrogen and carbonic oxide have recently been found to liquify by condensation in the same manner. (*Philosophical Magazine*, July, 1883, page 76.)

Dr. Perry, in the Inaugural Address at the Spring meeting of the Iron and Steel Institute, in May, 1885, observed: "The nitrogen iron and steel question should, I think, by no means be regarded as fully disposed of, for which opinion, if time permitted, I would assign my reasons at length. Why is it that in the process of case-hardening iron, animal matter, or certain other substances rich in nitrogen, should always be employed? *Is any nitrogen or any compound of it*

imparted to the case-hardened part of the iron?" (*Iron*, May 8, 1885, page 404.)

We would ask, is it the carbon that leaves the oxygen and the nitrogen, (or carbonic oxide) and combines with the hot iron and turns the surface to steel?

If nitrogen be a stable form of carbonic oxide, but still decomposable in the laboratory of organized beings, the great difficulty which seems to occur, as to how plants obtain their large supplies of carbon, from the minute amount of it heretofore supposed to exist in the atmosphere, would be removed. It does seem almost incredible, although it is the orthodox belief to-day, that a mile square of sugar cane, for instance, which grows in a year, and which will yield 3,000 tons of sugar, and of which the cane, leaves, roots, etc., would weigh at least 36,000 tons, should obtain the 4,000 tons, more or less, of carbon in its composition, from the atmosphere, which is supposed to contain but a little over one part in 10,000 of this element.

It is true that the weight of carbon in the air over a square mile of surface has been estimated at not less than 13,800 tons, but this is diluted through forty miles high of air, and although winds and the diffusion of gases may do a great deal, it is difficult to imagine how the cane leaves, averaging say five feet high, from the ground, could *get at* such a quantity of carbon in the time and extract it from the carbonic acid of the atmosphere, of which it composes only the 2,500th part.

Dr. Sterry Hunt, on a general review of the carbon question, (*American Journal of Science*, May, 1880, page 349,) finds it necessary to appeal to the ether of the interstellar spaces as the possible source of the continued supply of it, it being constantly abstracted from the atmosphere and locked up in graphite, coal, lignite, limestome and solid rocks, as carbonates of different kinds.

If, however, nitrogen should be, as Mr. Kilgour believed, a stable form of carbonic oxide, but decomposable by plants, we need not appeal to an extra-terrestrial source for a liberal supply of carbon for them, and of which indeed their solid parts principally consist.

Bischof places carbon in the same category as sulphur, that is, as a secondary product: and says: "In the isolated condition can therefore only be regarded as a product of decomposition of carbonic acid, and it is the vegetable kingdom which yielded and still yields this product." (Chemical and Physical Geology, by Gustav Bischof, London, 1854, Vol. I., page 252.

It seems well worthy of note that sulphur, sulphuretted hydrogen, nitrogen and carbonic acid should be the main products of volcanic action (except atmospheric air and the vapor of water) which arise from the orifices in a gaseous state, and that they are also the main products of the decomposition of animal and vegetable matter.

These products may no doubt be sometimes the result of their distillation by volcanic heat from sedimentary beds containing organic re-

mains. In the case of Kilauea and Mauna Loa, however, and other strictly oceanic volcanoes, we have no right to appeal to hypothetical beds of sediments containing organic remains, and even if we might do so, this process of distillation could not continue in one place through long ages.

May it not be possible that volcanoes obtain these materials—hydrogen, nitrogen, carbonic acid and sulphur—from the same source that plants and animals do, namely, from the atmosphere, and that as almost all chemists have reported, volcanoes mainly exhale what they inhale, that is air and water, but deoxydized, decomposed, and, as we venture to suggest, in some instances re-composed, by the intense heat and pressure acting upon the nascent elements.

Vegetable and animal life and volcanoes appear in the same predicament. They give out, so to speak, certain elements which we believe they get from the atmosphere, and certain others which it is difficult to believe they can get from that source, and yet there is no other feasible one to point to. Does the heat and pressure and avidity for oxygen, of molten iron lavas, act like organization in decomposing compounds derived from the atmosphere (including water), and in recomposing others from its elements?

It is further remarkable that carbonic oxide, carbonic acid and nitrogen seem to be again associated together in the tails of comets, whilst sulphur is found in combination with the solid parts of aerolites. Carbon, sulphur, and their compounds, and nitrogen, have not we believe yet been found by spectrum analysis in the sun, but they all appear together in aerolites, comets and volcanoes.

A molten planet composed largely of basic iron lavas, or of the minerals of meteors, and at a white heat, would at first be subject to tremendous convection currents. The atmosphere, whatever composed of, would be drawn in with these and would be subjected to intense heat and pressure, and to a vastly greater extent than we now see this kind of Bessemer process carried on at the lava lakes of Kilauea. We will merely throw out the suggestion to chemists, whether our present atmosphere, or we should say perhaps, the original atmosphere of the earth, when the surface had first cooled over, may have been the result of this kind of action on a cometary atmosphere, and then of the subsequent action of plant life. Does not everything point to an excess of carbon in the early atmosphere, in some shape or other? But if Kilgour was right in his surmises that nitrogen is carbonic oxide in a stable form, the atmosphere may have been just as well suited to animal life, in early times, as it is to-day, the only difference would have been, that there was then a greater quantity of atmosphere altogether. But this is in the highest degree probable, on any view of the subject.

It seems indeed, to be in this direction that we should look for a large part of the warmth, moisture and equability in the climate of former geological epochs, in view of Dr. Tyndall's experiments on

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radiant heat, rather than a change in the position or in the inclination of the earth's axis of rotation. At any rate, all the elements (so-called) now treated of as arising from volcanoes in a gaseous form, and existing in the atmosphere, are being continually deposited and preserved in a solid state, in new combinations. Of these carbonate of lime seems to be by far the most important, and in view more especially of the recent ocean explorations, indicates an enormous lock up of oxygen and carbon. At the same time—as most chemists have pointed out—the issue of the different elements in the form of gases from volcanoes, cannot be considered as indicating tbe source of them, but only as a circulation of the components of the atmosphere, including, of course, water. The atmosphere then, is constantly decreasing in quantity; or it has been constantly greater in quantity as we go back in time; whilst if nitrogen be stable carbonic oxide, we escape the difficulty of supposing the former co-existence of animal life, with an excess of carbonic acid in the atmosphere, and still have a source for the enormous masses of locked-up carbon.

APPENDIX TO CHAPTER IV., PAGE 104.

The following extracts from the recent work, "Synthese des Mineraux et des Roches," par F. Fouque et Michel Levy, Paris, 1882, and which we have ventured to translate, seem almost decisive in favor of the general proposition that the ultra-basic minerals olivine, labrador, as well as anorthite and the basic feldspars and augite —the components of olivine-basalt—are the result of pure igneous fusion, whilst most, if not all the more silicated minerals and quartz itself, are the products of promorphism and metamorphism, or of heat and pressure *with water*, atmospheric action, and the various re-agents which water and air may contain:

They say (page 13): "Direct experiment has permitted us to increase considerably the number of rocks of which the formation must be referred to pure igneous fusion, and to include with certainty basalt and all the modern volcanic rocks" (basic?) "On the other hand, the importance of all the methods employed up to to-day to re-produce granite, granulite, the porphyries, and in general all the acid rocks, shows that nature has, to produce them, put in action a method different to those which are in use up to the present in our laboratories."

(At page 19) They show that Elie de Beaumont was amongst the first to claim a mixed origin for granite.

(Page 32) "M. M. Friedel and Sarasin have recently obtained the association of quartz and orthoclase by heating the constituent elements of these minerals in a close vessel, *in presence of alkaline water.*" (The italics are ours).

(Page 63) "In fine, we have produced (by pure igneous fusion) in a mass of about 14 grammes, an artificial basalt identical in all respects with certain natural basalts, and in particular with that of the plateaux of Auvergne. It is true that our product did not contain water; but *microscopic researches have shown that that of the natural*

basalts was connected with secondary alterations, of which the olivine is the principal object. Our experiments settle definitely, then, the question of the origin of the basalts; they are rocks of pure igneous formation.

(Page 78) "In the same way, a mixture of *hornblende* and of *oligoclase* was transformed (by fusion) into *augitic andesite.*

"These negative experiments prove that the natural rocks of quartz, orthoclase, black mica, hornblende, seem to be formed in another manner than by pure igneous fusion."

(Page 79) "By the side of rocks of pure igneous fusion, there exist some closely related ones, but for the reproduction of which our methods are shown, however, to be powerless. Such are *hornblende andesites, trachytes with black mica,* and phonolites. We may remark that these are already acid rocks, and that the domain of the igneous method comprises specially the basic rocks."

(Page 88.) "However, if we observe that tridymite abounds in certain modern lavas, such as the lavas of Santorin for example, which are far from being supersilicated, we shall attribute, in certain cases, the origin of the natural tridymite to the intervention of a method of operation analogous to that which has been employed by M.M. Friedel and Sarasin. Such an opinion is further corroborated by this fact, that in the layers of tridymite in the midst of lavas, the secondary action which the water has exercised, is incontestable; it has engendered various products of alteration, and that under the eyes of the observer."

(Pages 138 to 142.) Anorthite and labrador and oligoclase are shown to result from pure igneous fusion, but (page 142,) 'it results from our experiments that orthoclase and albite, (the silicated feldspars) are not reproduced with the same facility as the other feldspars, by the igneous method. In general we have found that a feldspar is the more easily crystallised by the igneous method, the more basic it is.'

(Page 158.) "Our experiments render an account of the presence of oligoclase, of labrador and of auerthite in the rocks of eruptive igneous origin and in meteorites. Those of M.M. Friedel and Sarasin may explain the orthoclase of the ancient eruptive rocks, that of metamorphic rocks and that of concretionary veins."

(Page 100.) "Normal olivine is a mineral which is only met with in rocks of igneous origin; volcanic rocks, chrysolites, meteorites. The experiments of Berthier, of M. Daubree, and ours, show that it is produced by crystallization in the midst of a molten magma."

In fine, this valuable work of M.M. Fouque and Levy, may be said to be throughout, an experimental exemplification of the fact that olivine-basalt and its minerals are the result of *pure igneous fusion,* and that nearly in proportion as the minerals and rocks became more silicated than these, by so much is the action of chemified waters found to be necessary to their production; whilst all the minerals of what are generally classed as metamorphic rocks, and some that have

not hitherto been so classed—diorite for example—fail to show themselves capable of reproduction by igneous fusion. Bischof is thus confirmed in his important axiom, that there is no single ground for believing that hornblende is the product of fusion; and these gentlemen have now placed fairly before geologists and mineralogists—what Bischof despaired of finding—a rock formed from fusion which contains the minerals from which, with the addition of sulphur and the elements of the atmosphere and water, nearly all other minerals and rocks may be derived by metamorphic action. We use "metamorphism" as the general term for all mineral changes, as Prof. Dana has suggested in an article in the *American Journal of Science* for July, 1886.

APPENDIX TO CHAPTER VI., SECTION 2, PAGE 144.

On the relation between the age and the mineral composition of the volcanic and other rocks of the Pacific Slope of North America and elsewhere, according to Von Richthofen, and its bearing on the general subject. Dr. J. Petersen and J. J. Harris Teall, on "Augite-Andesites," "Enstatite-Porphyrites," and other volcanic rocks of the Cheviot Hills:

We have, in the text, traced the gradual passage (by the evidence of experts) of the Hawaiian ultra-basic lavas to a more "trachytic" or "feldspathic," or to an "andesitic" character, as the mountains are older, or as the lavas have been longer exposed to atmospheric influences. All these volcanoes are probably of recent formation. For more ancient basic volcanic mountains, however, we have only to go over to the neighboring Pacific Slope of the North American Continent. Let us see what Baron Von Richthofen, and more recently, the gentlemen of the U. S. Geological Survey, have to report on the volcanic rocks there:

Baron Von Richthofen's account ("The Natural System of Volcanic Rocks, San Francisco, 1868,") of the order of succession of the volcanic rocks of this region does not attribute the mineralogical differences to a change having taken place in them after eruption, but merely notices the fact of a regular order of succession, assuming them to have been erupted with their main characters as we see them to-day. This order is as follows, and it is one that is now admitted to be common in all parts of the world: (See "Natural System of Volcanic Rocks," page 29.)

"The latest erupted is usually basalt. The next earlier is rhyolite. The next trachyte, then andesite, whilst the earliest of all (the oldest) is propylite. This order is, he observes, relative to the age of *Massive* Eruptions,"

Of the above five eruptive rocks, our theory makes rhyolite and trachyte (with sanadin) to be the product of "promorphism," or the result of the action of aqueo-igneous fusion on basic molten lavas. These two lavas therefore, appear in their proper order if they may be looked upon as the effect of underground water on molten basalt, and

much of which basalt had, previous to the change, been erupted over extensive regions, but appearing to-day converted to propylite, to which rock, as we have shown in the text, (Chapter IV) Richthofen says, trachyte and rhyolite are always found subordinate.

The other three lavas, basalt, andesite and propylite, judging from what we observe on the Hawaiian Group, we should consider to be respectively basalt, the upper layer of the original cosmical basic magma, next below the crust. Basalt, deprived of part of its bases and new minerals added by ordinary metamorphism at ordinary surface temperatures; and basalt which has undergone still further metamorphism, or a conversion to the verge of being a true diorite, which we look upon as a basalt or dolerite, with all the augite completely converted to hornblende, whilst the labrador has been also usually converted into a more silicated triclinic feldspar.

Propylite is indeed, according to Richthofen, "the precursor of all other volcanic rocks," (p. 22) following the view prevalent on the Continent of Europe, that there are no clearly distinguishable ancient (pre-tertiary) volcanic rocks; and it is generally admitted that they have largely disappeared—at least with their original characters.

Baron Von Richthofen observes that, "propylite has been repeatedly considered to be a sedimentary rock metamorphosed *in situ*," but he considers that it is truly eruptive, (page 22.) The explanation we propose is, that it is eruptive and afterwards metamorphosed *in situ*. It is a further stage of the change we have already seen to be affected on ultra-basic lavas on Hawaii, and a nearly completed instance of the conversion of basalt or dolerite to diorite, and is in agreement with Mr. R. D. Irving's observation that all the hornblendes of all the greenstones and of all the hornblendic gneisses, schists, syenites and granites, that he has examined, were secondary to augite, (see Chap. IV., p. 67.) When further silicated it may become quartzose propylite or dacite.

The recent observations of the mineralogists and geologists of the U. S. Geological Survey on propylite, are very instructive. One desires to "discard the name propylite from American Geology," on the ground that it is nothing more or less than a diorite, whilst another would do so (G. F. Berker, in *American Journal of Science*, Dec., 1883, page 480,) because it "was proved to be an altered rock, either andesite or diabase," thus connecting it with the lavas. Richthofen himself explained that "it belongs mineralogically to diorite and geologically to volcanic rocks."

Propylite seems indeed, to well deserve its special name. It is the link in metamorphic action, between the basaltic lavas and the traps, sometimes containing the original augite which connects it with the lavas, and sometimes the hornblende which is derived from augite by metamorphism, and connects it with the traps.

In truth we may have to revert to the principle of being guided, to a large extent, in naming the rocks, according to their age or position

in the series. It is an immensely important factor, if nearly all rocks were originally basalts. Baron Richthofen shows again and again, that the augitic propylites are invariably the more recent, and the hornblendic the more ancient, and which agrees with the universal testimony as to the relative general sequence of these two minerals, although this does not, on the theory now advanced, prevent us from expecting sometimes to find augite, or labrador or olivine, in the very oldest rocks. Further he observes (p. 23) "that the entire range of quartzose to augitic varieties (of propylitic rocks) was anterior in age to andesite," the rocks from which (or on the verge of which) we parted (in the text,) in the older, but still recent, volcanic mountains of the Hawaiian Group, the most recent being olivine—or ultra-basalts.

Having thus followed the changes of basaltic volcanic rocks by ordinary metamorphism *in situ*, and in accordance with their age, from the ultra-basalts of Hawaii, through andesites to the propylites of the Pacific Slope, and to the verge of diorites—may we not say to diorites—in North America, it would be presumption in us to do more than remind geologists of what they one and all inculcate, that the steps from a diorite through quartz-diorite to a syenite and to a hornblende granite are insensible, and that the actual transitions by metamorphism are often apparent, and that these transitions are usually in one direction—increase of silica or loss of lime and bases—and what is of the main importance—that this change generally occurs as the rocks are lower in the series or more ancient. That it still proceeds in buried strata on the same lines, till the most silicated schists, gneisses and granites are found. Or, in the words of Von Cotta, (p. 386,) "Crystalline schists," (which are constantly found passing into gneiss and granite,) "have lost their lime and magnesia in solution (for the most part in combination with carbonic acid) and which have then been separately deposited in the form of independent beds of limestone and dolomite"—the proposition with which we started as the main cause of change in all rocks, and the fate more especially of the basic lavas—the cosmical rocks—which are the most susceptible to the change by such an agent, (see Chap. IV.)

We have just read with much interest Mr. J. J. Harris Teall's review of Dr. I. Petersen's paper on the Enstatite-porphyrite of the Cheviot Hills, and which Mr. Teall "first recognized" (although probably of Old Red Sandstone Age) "as belonging to the group of the so-called augite-andesites" (*Geological Magazine*, May, 1884), and lavas similar to which are supposed to issue at the present day from the volcanoes of Santorin, and believed by M. Fouque to have been subject to the action of water. Mr. Teall observes: "In the Cheviot district we have an immense development of rocks to which every one would apply the term porphyrite. These are all of them more or less altered. Indeed it is their alteration which gives many of them their distinctive characters. Inasmuch as these altered rocks have a distinct character of their own, I see no objection to giving them a distinct

name." Again: "I may say, *en passant*, that I have seen among porphyrite rocks that I should describe as altered augite, hypersthene, hornblende and mica-andesites."

Whilst Dr. Petersen contends for the importance of considering the age of a rock in giving it a name, Mr. Teall shows why, or at least indicates the fact, that augite-andesites may be converted by metamorphism to other varieties of andesite and to porphyrites—an operation which requires *time* as well as circumstances. The two propositions are in accord. On the principles we now advance, all these rocks from augite-andesites to porphyrites, may have originally flowed as olivine, or ultra-basalts, and we have traced the changes—probably by ordinary metamorphism *in situ* in proportion to age, to propylites and diorites. The Cheviot rocks seem to establish the connection between certain molten basaltic lavas—augite-andesites—and the old porphyrites, by the same process of metamorphism. Whilst a diorite is a definitely metamorphosed basalt or dolerite, a porphyrite seems to be an indefinitely metamorphosed basalt, and may include, as Mr. Teall intimates, augite-hypersthene, hornblende and mica-andesite, that is, both the original and the secondary minerals resulting from their conversion. (In the conclusion of Dr. Teall's paper in the *Geological Magazine* of June, 1883, on the Cheviot Andesites and Porphyrites, he calls special attention to "the fact that some of the normal porphyrites are merely altered andesites.")

The general course of metamorphism throughout geological time has been, both in the rocks and in their component minerals—and a large number of exceptions in a contrary direction under special assignable circumstances does not affect the rule—from the anhydrous, unstable and basic, to the silicated, stable and hydrous; with the substitution of the less soluble potash for the more soluble alkali soda. (J. J. Harris Teall on the Scope and Methods of Petrography.)

Since writing the foregoing we have perused Mr. J. J. Harris Teall's article on the Cheviot-Felsites and Augite-Granites in the *Geological Magazine* for March, 1885, as well as the report—in *Nature* of March 12, 1885—of a lecture delivered by him in the Woodwardian Museum, Cambridge. In these we note a corroboration of many of the views and suggestions we have made in our Chapter on Volcanoic Action and Volcanic Rocks. For instance he observes: "We are profoundly ignorant on questions relating to the origin and sequence of volcanic rocks, the cause or causes of volcanic action, the mode of formation of the crystalline schists, and the origin of mountains." (*Nature*, March 12, 1885, p. 444.) Again he says: "Consider the case of an internal reservoir of molten rocks, and for the sake of simplicity, suppose the conditions of crystallization to be realized in the upper portion. The basic minerals will form and then fall by reason of their high specific gravity. On descending to lower levels, they may be dissolved, and thus a variation in the composition of the originally homogeneous magma may be produced. (*Geological Magazine*, March, 1885, p. 119.) This is just

what we assume to have taken place in the Palolo dyke, Oahu, and what may take place in the molten rock in the conduits on Hawaii. The subsidence of the heavier basic minerals may reduce the specific gravity of the column, and what is specially to be remembered, this action may go on in one column to a greater extent than it does in another, so that two connected columns may stand at different heights. Mr. Teall goes so far in this hypothesis as to suggest (page 119) that "Rocks of rhyolitic composition may represent, so to speak, the mother-liquor out of which the basic minerals have crystallized." We have it is true, proposed the hypothesis of the subsidence of the basic minerals in the Palolo dyke—after it stopped overflowing—being the cause of the composition of that dyke being less basic than the surface flows which may have proceeded from it; but it still remains a basic rock. To form rhyolites we have proposed, what indeed Mr. Teall refers to further on (page 120), "the influence of water," but of which the Palolo dyke shows no indication. We have imagined the original magma from which all rocks and minerals have proceeded to be ultra-basic, and that the basic minerals have been largely removed, both by subsidence and the influence of water, thus producing an acid series. Those who consider that there are evidences of a general upper layer of silicated molten rocks—an *ecume-siliceuse*, may prefer to look upon the basic minerals and rocks as having drained away from this. We think the weight of evidence, however, to be in favor of a universal ultra-basic substratum from which all rocks have proceeded, and by assuming this, the difficulty which occurs to Mr. Teall (page 120) that "That sequence of volcanic rocks is, however, usually complicated by the introduction of basalt during the later phases of volcanic activity"—disappears; for this is just the effect to be expected on our hypothesis wherever the expulsion of the molten matter may have been continued long enough to exhaust the locally formed silicated rocks. At the same time it need not cause surprise if in certain cases the expulsion happened to cease before the complete exhaustion of the silicated magma.

Another interesting point "almost in the nature of a paradox," referred to by Mr. Teall is this (page 120): "The fusion point of basic rocks is lower than that of acid rocks, and yet minerals separate out as a general rule in the order of their basicity, the more basic being the first to form. How is this to be explained?" We venture to suggest the following considerations in connection with this point. In an anhydrous ultra-basic fused magma, composed say of (potential) basic feldspars, augite, olivine and magnetite, the non-ferriferous olivine, and magnetite are at the same time the most basic and the least fusible minerals, so there is no difficulty in their case, if we find them to have been the first formed. The infusibility of a rock or a mineral depends more perhaps on the simplicity of its composition than on its acid character. An alloy of two metals has usually a lower fusing point than that of either metal by itself. Many basic rocks and basic min-

erals contain nearly all the usual rock-forming substances, including lime, which is a noted flux. As lime disappears the minerals and rocks become less fusible. Olivine and magnetite are simply compounded minerals and contain no lime. They are therefore—although highly basic—amongst the more infusible and tend to crystallize, and being heavy subside first. Thus the removal of basic elements is often a first effect in the ultra-basic molten rocks, which have cooled slowly in large fissures, rocks or dykes.

APPENDIX TO CHAPTER VI., SECTION 2, PAGE 144.

On the relation which exists between the minerals of the volcanoes of northern California, Oregon and Washington Territory and those of the Hawaiian Group.

In the *American Journal of Science* of Sept. 1883, there appears a short notice by Arnold Hague and Joseph P. Iddings, of the U. S. Geological Survey, of the principal rocks and minerals found in the four great volcanic mountains of Lassen's Peak, Mount Shasta, Mount Rainier and Mount Hood, which are taken as typical of a great volcanic range five hundred miles long in California, Oregon and Washington Territory. They say:

"All these rocks then, may be classified under the following heads:

"*Basalt*, composed of plagioclase, augite and olivine as essential minerals.

"*Hypersthene-Andesite*, having plagioclase, hypersthene and augite as essential minerals.

"*Hornblende-Andesite*, with plagioclase, hornblende and pyroxene as essential minerals.

"*Dacite*, composed of plagioclase, mica, hornblende and quartz as essential minerals."

It seems to be well worthy of the attention of petrologists, that these gentlemen look upon the hypersthene as related to, and a substitute for, the olivine in the basalts, it having "a somewhat higher silica percentage, the former mineral being, as it is, simply the bi-silicate of the same Fe. Mg. elements."

These continental volcanoes seem indeed to be largely composed—besides the usual olivine-basalt—of a more silicated basalt than that which appears in the volcanoes of the Hawaiian Group, whilst much of the olivine or augite, or both, appears to have been converted to hornblende. Which of these transmutations (and silification) have occurred before or after eruption, and how, is a most interesting question. When we come to the dacites, however, or "quartz-mica-hornblende-plagioclase rock," the influence of local water seems to be very strongly indicated, both by the presence of quartz and tridymite, and the prevalence of gas bubbles in the glass globules.

It is further worthy of note that these observers remark (page 233) how the olivine-basalts shade by insensible degrees into olivine-bearing hypersthene-andesites, these into hornblende-andesites, and finally

into quartz-bearing andesite, or dacite. A further analogy may be noticed between these North American volcanic rocks and those of the Hawaiian Group. Messrs. Hague and Iddings say, in the same paper (page 234): "It will be remarked that no mention has been made of augite-andesite; among the andesites in this collection from the volcanoes, none have been found in which the predominating pyroxene is augite."

The principal *outflows* on Hawaii—but not the great central dykes and bases—seem to be mainly composed of plagioclase and olivine, which latter mineral is represented in these continental volcanoes by the bi-silicate hypersthene, that is—may we not say—by a silicated olivine, augite being very scarce in both.

M. Daubree has shown. ("Synthetic Experiments Relative to Meteorites," translated and published in the Report of the Smithsonian Institute, 1868,) that the addition of silex to melted olivine will produce the bi-silicates, and that even when olivine is melted in a crucible it may borrow silica from the lining and form bi-silicates, such as enstatite and hypersthene. These facts may have an important bearing on great physiographic questions, because if it should appear on further examination, that in the lava of the continental volcanoes hypersthene and other bi-silicates largely replace the olivine characteristic of the lavas of the strictly oceanic volcanoes, it would indicate that the universal molten olivine-basalt may have come up through the old, highly silicated and granite strata on continental areas, but has not passed through such formations on central oceanic areas. That is to say, the facts, as far as they go, tend to show that granites, gneisses and other highly silicated rocks, do not exist even in the lower strata composing the great central ocean beds, and which absence we have assumed throughout, is probable on other grounds.

APPENDIX TO CHAPTER VI., PAGE 151.

On Terrestrial Accidents about Twenty Miles Apart.

We have referred in detail in the text to the fact that the intersecting lines of volcanic fissures seem to be about twenty miles apart, or at least that those which exhibit themselves in oceanic islands and above the sea level, are at that distance apart, or multiples of that distance, and that the grand volcanic orifices are at the points of intersection of those fissures. We have further suggested why, on the general hypothesis, the main craters should appear at such intersections, and why the crater should be elliptical in form, with the longer axis of the ellipse on a line at an angle precisely intermediate, between the smaller angles formed by the intersection of the two fissures which produced them.

But these features in the earth's crust are not confined to oceanic islands. They appear to be common ones over the whole globe. If any one will take a good map or chart of the Greek Islands, and open a pair of compasses to twenty miles by the scale on the map, he can

start at any part of the Archipelago, and placing one leg of the compasses on the centre of one island, or on the centre of one closely connected group of islets, he can step from one island to another, or from one closely connected group of islets to another, without altering the opening of his compasses, and not miss one important island of the group of islands. But the same opening connects the archipelago in two places with the main land. It connects also Cerigo with the main land, Zante with the main land, and Cephalonia with Maura, Maura with the main land, and Ithica with the main land. It closely represents the average width of all the numerous gulphs of the Greek Peninsula, and the width of the small peninsulas projecting from it. Many of the main chains of mountains are about twenty miles apart, whilst Attica, Thebes, Lacedemonia and Corinth, States which no doubt have originally had their boundaries defined in accordance with the natural features of the country, are each about twenty miles average width. If we now turn to the map of Italy and open our compasses twenty miles by the scale on the map, we shall find that the gulfs and small peninsulas of Italy range round twenty miles wide. Many of the small States are about twenty miles wide, whilst the Dalmatian Archipelago, on the opposite side of the Adriatic, seems to be composed of islands ranging round the distance of twenty miles long, and all situated within a distance of twenty miles from the main land. Again, a distance of twenty miles will take us from one bay or harbor to another in Ireland. For instance, from Cork to Yougall, Cork to Kinsale, Baltimore Harbor to Bantry Bay, there to Kenmare River, there to Dingle Bay, there to Tralee, there to the mouth of the Shannon, and so on with more or less exactness all round the coast. But the same thing may be found in Scotland, and to a less extent in England. Lochs, lakes, firths and islands, show a marked disposition to be twenty miles long, or multiples of twenty, or to turn at an angle at distances of twenty miles. Reaches of many large rivers show an inclination, after running twenty miles, to turn at a new angle. In fine, it seems as if twenty-mile accidents, such as we have referred to, the result of fissures and faults on fissures, and often volcanic outpours at the intersections, are characteristic surface features of the globe, and may well be determined by the thickness of the crust affected. If any better reason for the fact—if it be one—can be assigned it would be satisfactory to have it presented.

On continental areas the twenty-mile accidents are apt to be obscured and deranged by sediments, by erosion, and by the crushing and contortion of strata, but in oceanic islands they are left comparatively undisturbed. On many continental areas however they are clearly indicated. The effect is perhaps more readily traced in Greece, Italy, Great Britain and Ireland, although they belong to continental areas, because their insular or peninsular character allows the waters of the seas about them to clearly exhibit the contour lines on the maps.

It may be surely predicated, when we find the surface features of the

oceanic islands, the Greek Islands and the British Islands, tending to be divided up on one general pattern and scale, that there is one and a planetary cause for it. As the contour lines shown on our maps by the ocean waters on the continents, indicate the figure of the earth, or rather the particular deformation of the spheroid, and the probability that the earth's crust is thin and flexible, so may the contour lines exhibited by ocean and other waters on the smaller details of that crust, indicate the superior limit of its thickness.

APPENDIX TO CHAPTER VI., SECTION 3, PAGE 152.

On the Melting Temperature of Rocks under Pressure.

With reference to this question—that is, the depth at which we may expect to find rocks in a molten state, estimating from the observed regular rate of increase of temperature as we descend, it would seem remarkable to what an extent incorrect assumptions have been allowed to influence geologists. It has been constantly assumed as a settled point, that the substances which we should expect to find molten in the interior of the earth, have their temperature of fusion raised by the pressure to which they must be subject at great depths, and therefore, that the matter in the interior of the earth, probably assumes the solid state at temperatures which at the surface would fuse them. The contrary proposition seems more probable.

It is now generally recognized that substances which, like water, iron, and many other metals, expand at the moment of solidifying, are kept in a molten or liquid state by pressure, the temperature of fusion is lowered instead of raised. It has been ascertained by experiment that the compression of water will delay its conversion into ice. Analogy leads to the conclusion that all substances which expand at the moment of solidifying, will rather be kept in the molten state, than be solidified by pressure.

Certain experiments made many years ago on the temperature of fusion of spermaceti, wax and other similar substances, showed that their points of fusion were raised by pressure, and although some substances behaved in the opposite manner, and the experiments generally were inconclusive and unsatisfactory, they seemed sufficient to confirm the idea of most British geologists, that the great pressure in the regions below the crust would cause all the rocks to be solid, although at temperatures far above their fusing point at the surface of the earth.

The interior of the earth, however, does not consist of substances like wax or spermaceti, but probably, as we have seen, of a basic magma of fused minerals and metals—largely iron—most of which are now known to expand at the moment of solidifying. Certain experiments of Mallet's on the contraction of slags have been appealed to, to show that slags at least do not expand at the moment of solidifying. It was always evident, however, that his experiments merely showed that slags contracted on the whole, in passing from a high

temperature and molten state to the solid state and to the temperature of the atmosphere. Just, in fact, as iron has long been known to do—and yet the weight of evidence is in favor of the view that iron expands a little at the moment of solidifying, and that this is the cause of its making sharp castings.

The late Mr. Mallet's defense of his position, that most substances, including slags, do *not* expand at the moment of solidifying, may be found in *Nature*, June 25, 1874, page 156, but it is clear that he only claims, in the case of cast iron for instance, that it is more dense in the *cold* solid state than in the molten state, which nobody now denies.

Lately, the experiments of Whiteley, T. Wrightson, J. B. Haunay and others, seem to show that siliceous slags, as well as iron and most metals and their alloys (see *American Journal of Science*, Feb. 1881, p. 147,)—and of which the interior of the earth is probably composed—behave just as ice and iron have long been known to behave; that is, when in a fluid state they contract from cooling until close to the temperature of solidification, when they slightly expand, and after solidification they all contract again by further cooling. (See a paper in the London, Edinburgh and Dublin *Philosophical Magazine*, for May 1882, on the "Fluid Density of Certain Metals," by W. Chandler Roberts, F.R.S., and T. Wrightson, Memb. Inst. C. E. The gist of these experiments however, as bearing on the present question is contained in the following quotation, (p. 367.) "They (M.M Nies and Winkelman,) arrive at the general result, that not one of the eight metals they examined will justify the assertion that "bodies contract upon becoming solid," but the experiments rather favor the view that metals when solid, *at a temperature close upon their melting-points*, are less dense than when molten." It is perhaps hardly necessary to note the fact that the heavier ingredients of a molten magma often crystalize first and then sink, does not in any way weaken the result of the experiments referred to above. Crystals of heavy elements may well have expanded a little at the moment of solidification, and yet be more dense than the remaining fluid magma from which the heavier ingredients had separated. For instance, olivine and magnetite may easily sink in a more siliceous magma, and it has been observed by Darwin and others that even feldspar crystals will sometimes sink in a *glassy* basic magma, the reason for which—still in accordance with the principles now presented, being, that the specific gravity of the elements and their combinations going to form the feldspar, is greater than that of those which remain in the molten glass—now rendered more siliceous by the withdrawal of lime and other heavy bases by the feldspar crystals.

Basic lava seems to follow the same rule, it may float when solid, but very hot, and in a state of glass, on the surface of the molten mass on which it solidified, but when it has slowly cooled to the temperature of the atmosphere and has become devitrified, it will sink in very

hot molten basic lava, and experiments and observation by different persons on Hawaii and elsewhere, (Johnstone Lavis, *Nature*, May 15, 1882,) shows that this is the case. And yet the minerals and metals composing it, probably also follow the general rule of expanding at the moment of solidification.

Bearing these facts in mind we see:

First. That pressure from depth probably helps to keep the molten interior in fusion rather than causing it to solidify, as the text books have been in the habit of teaching.

Second. That while there is no difficulty in understanding how a solid, but glass-like crust may first form over a basic lava, and there float, there may arrive a time when from its increasing thickness and consequent average coolness and devitrification, it may become more dense than the molten lava on which it rests, and from which it solidified.

APPENDIX TO CHAPTER VI., SECTION 8, PAGE 179.

Personal Reminiscences and General Remarks concerning Hawaiian Lavas and Volcanic Gases, Vapors and Explosions.

In 1859, on the evening of the day referred to in Chapter IV., I started with two guides—goat-hunters—to visit the orifice of eruption, of the lava we had been observing spreading itself over the plateau between the mountains Loa, Kea and Hualalai. We camped about 9 o'clock on the flat between these mountains close to a portion of the lava stream which was spreading itself plentifully over the ground, and all night long we heard loud explosions like the reports of heavy cannon. At the time I did not know the cause of them, but on my return I happened to be close to an explosion under a stream of lava, and which was evidently caused by the white-hot molten lava flowing over a hollow in one of the innumerable old lava streams. It is to be observed that in this part of the mountain there is no water. All the apertures of some underground cavern having been sealed up by the molten lava, it is only a question of time how soon an explosion of confined highly-heated air will occur. The molten lava may sometimes run into these caverns and so assist both the heat and compression. I heard the same noises at a distance up in the mountain in 1868, when I visited the flow at Kau in that year. Mr. Hitchcock reports the same kind of explosions on the flat near Mauna Kea at the flow of 1880, and attributes them to the same cause.

In 1867, I was passing Kilauea on my way to Kau with the late Captain Thomas Spencer of Hilo, when we heard an unearthly intermittent shrieking down in the crater, something between a human shriek and a locomotive whistle. We went to the edge, and looking down perceived a hole in the hardened crust of a recent lava stream, around which broken pieces of lava were distributed. It was evidently from this opening that the shrieks proceeded, but we could see nothing whatever coming out of it. I went down into the crater and got as

near to the opening as I dare, but the crust near the hole became very hot and suspiciously smooth and hollow sounding. The intermittent shrieks continued, but I could not see a trace of steam or vapor. I was well aware that super-heated steam may often remain invisible, but if it had been escaping steam which caused the shrieking, there should, I think, have been some visible evidence of it after it had expanded into the cool mountain air. Whilst thus watching, an explosion and shriek of extra violence occurred, which blew away a further portion of the lava crust about the hole, and the fragments fell all round me, and which induced me to make a rapid change of base. I cannot doubt that the cause of these intermittent shrieks was the result of air which got entrapped in the hollows of the cavern by the running molten lava, and which discharged itself as it got sufficiently heated and expanded.

In 1860, when I spent the day alongside of Halemaumau, down in the crater of Kilauea, a so-called blowing-cone at some little distance from the lava lake was constantly discharging *something*, with intermittent reports like dull pistol shots, I could never see anything proceeding from it, and was surprised that I did not observe indications of steam, I have since come to the conclusion that these reports were the result of confined and heated air.

In 1873, being at the crater of Kilauea with Miss Bird, I had an opportunity of looking for an instant into a cone and blow-hole which happened to remain quiet while we were there. It was close to the lake of Halemaumau, and was situated over a cavern which evidently communicated with the molten lake. The top of the cone, about nine feet high, was entirely covered by its own ejections, but there was an opening in the side about two feet wide, just about the height of my face, so that I could easily look in. That is, easily except for the intense heat, but by screening my face with my hat, and letting my hands be scorched, I got a view of the interior. The cone communicated with a cavern, the irregular roof of which seemed to extend at an angle of perhaps 30° for forty or fifty feet. All the interior was at a full red heat; along the bottom red-hot, or, rather, orange-colored; molten lava swashed about, just as the waves may be seen on looking into a blow-hole on the sea-coast. It was thoroughly protected from radiation and therefore kept molten. The roof of the cave was hung with red-hot lava stalactites—a simple result of the molten matter splashing up and dripping down again. I may remark that whilst the exposed surface of the lake of Halemaumau was on this day covered with a slowly-moving grey tough skin, the lava in this covered red-hot cavern connected with it seemed as liquid as water.

Here I may state that with my face for an instant just inside this contracted opening communicating by means of a covered passage with a lake of molten lava, I did not feel the slightest inconvenience from anything in the shape of gases, the intense heat alone preventing me from keeping my face at the opening. At other cracks, how-

ever, some little distance from the lakes, both Miss Bird and I were often half choked by sulphurous gases. It is probable that the draft of air at this opening may have been inwards, indeed it could not have possibly been outwards as it must have scorched me in an instant. On the other hand, if hot gases had been exhaled from the molten lavas, they would probably have escaped at this the highest, and what appeared to be the only opening in the roof of the cavern. From what I have elsewhere noticed, I believe that usually Hawaiian molten lava is comparatively free from noxious and sulphurous gases, except where decomposed and heated air—and in certain cases water—is returning by its expansion, or where it may communicate with the sulphur-beds around the crater. The noxious gases usually appear in hot cracks where we may suspect the molten lava to be near them on one side, and probably percolating water on the other.

I could not help being struck with the likeness of this blow-hole to those on our rock-bound island coasts, and believe that the machinery of both is closely alike. The waves, whether of water or lava, rush up the caverns, and after shutting in and compressing air, the latter ejects the water or the lava through the only available opening. On a coast the water is expelled in a jet of spray, whilst by the side of the lava lakes the ejected lavas build a cone as they fall in glassy clots. In the lava blow-hales the effect of compression is increased by the heating up of the confined air. Looking into this cavern, I could see opportunities for the action of heated and compressed air, for instance, in a branch of it there was a low opening which seemed to expand inside. It would not be necessary for any wave—strictly speaking—to come and close up such an opening in order to produce an explosion; a simple steady rise of the molten lava would be quite sufficient. The air inside heats and expands, and produces an explosion of mixed air and molten lava, throwing the latter out of the cavern and up through the opening, drenching the whole interior with the liquid from which it drains in stalactites a foot long. The lava being supplied from the lake, seeks its level again in the cavern, and the hollow having received a new supply of air, the operation is repeated. This in a variety of phases is, I can hardly doubt, the simple machinery by which the blowing cones of Kilauea, with their intermittent reports, shrieks, and explosions are actuated. Why should we look about for mysterious expansive gases, or even steam or the vapor of water, when we have everywhere a column of air ready to force itself into each opening? On the other hand, the white-hot fiery caverns exist everywhere about the crater underneath the crust, and the molten lavas seem always to be prowling about ready to fill them up; or, running off and leaving a hardened crust to make new ones. Whenever the outer air gets shut up in one of these furnaces, an explosion must sooner or later occur, as surely as would happen to a bladder full of air placed before the fire.

Yet so general is the idea of connecting such explosions with steam,

that some artists who are supposed to depict what they see, might often fill up the picture of these blow-holes in action, by showing the steam that they had no doubt was there; and more especially as in many places about the crater, real steam and real vapors are often seen, and when it rains or has rained heavily, and there is much hot lava around, the steam is blinding, as might be expected. Indeed, now and then a blowing-cone may be operated by steam instead of air.

I may observe here that some years ago one of our photographers, who took volcanic pictures for sale, principally for strangers, passengers by the Australian steamers, put what he considered to be the legitimate finishing touches to a whole set of photographs of the lava lake of Halemaumau, by manufacturing what showed as balls of white vapor rising from the centre of it, when full of molten lava. This has never been seen here. He afterwards admitted to Mr. C. Furneaux and myself that he did it because he thought it was all right, and that the pictures would sell better. I have carefully preserved one of these spurious photographs as a characteristic specimen of a phase of human nature, but not of one of the phases of volcanic action in Halemaumau.

In truth the photograph of one of these lava-lakes, and in which the red heat does not show, has often the appearance of a quiet Cumberland mountain tarn, and would seem to most passers-by in Honolulu, as hardly worth paying for to take home as a curiosity. There is no question however, that smoke and vapors often arise from blowholes, and we may ask, what becomes of the underground water which must be always percolating from the melting snows, or condensing clouds of the mountain around this great furnace of Kilauea; and does it take no part in these emissions of elastic gases down in the crater? In the first place the bulk of this water seems to be evaporated from deep chasms outside the edge of the crater. There is plenty of heat down below, and pure steam constantly arises in many places. This is often condensed again by placing objects to arrest it, and produces excellent drinking water for the use of visitors. But it probably is not all thus evaporated, the hot water standing below in the fissures, no doubt finds its way through the still hotter rocks nearer the crater, by capillary attraction, as explained by M. Daubree. The next emissions of steam at cracks just inside the outer rim of the crater are sulphuretted. Here are the steam and sulphur baths and the deposits of sulphur. Just what the connection may be—if any—between this percolating hot water, probably through red-hot rocks, and the emission of sulphurous fumes, I leave to chemists to answer.

But now, still further inside the crater and in the neighborhood of the molten lakes, where there are cracks, and often where there are blowholes, both invisible sulphurous, and dense white fumes will constantly but not always arise. These fumes in cracks around the edges of the lakes, may possibly be the last of the underground percolating water, although it is far from being pure steam, but rather appears to

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one who is not a chemist, as if it might be a gas arising from the decomposition of water or air, and mixed with sulphurous fumes and whatever dissolved components of the red-hot rocks it has passed through and may be mechanically mixed with. The impression I get from my observation of Hawaiian lavas and volcanoes—and it is only entitled to be called an impression, is in accordance with the views of the French chemists, who were appointed many years ago to examine into the subject; that volcanoes mainly exhale what they inhale, and that the larger portion of the exhaled gases about Kilauea, is partially decomposed air and water. On the other hand, the water, which under any normal state of affairs, could get to the lava-ducts which supply the great Hawaiian volcanoes, seems to be disposed of before it can have any important mechanical effect on the lavas. Should, however, a great white-hot fissure open under the sea, and let in millions of tons of sea-water, then we might expect another Krakatoa explosion.

But stupendous and dense columns of smoke almost constantly arise from the orifices of eruption on Hawaii, whilst at other times there is not a particle, notwithstanding that the lava may be pouring out as usual. When we pitched our tent on our way to the 1859 crater, in the neighborhood of the loud explosions already referred to, it being then quite dark, we had a fine view of the pillar of fire at the crater on the side of the mountain fifteen miles above us, and which all day had shown as a pillar of cloud or smoke. This at night became illuminated by the glare from the white-hot lake of lava in the crater. We were on our way to it early next morning, and although we did not rest more than an hour during the day, it was dark again when we arrived alongside the great pillar of fire which rose 10,000 feet at least above our heads. We had for some time been crunching our way over the glass-foam which had evidently proceeded from the great lava fountain which had now ceased spouting; and close to the crater a steep escarpment appeared, up which we climbed, and when nearly abreast of the centre of the crater, and a little below the level of the edge, we pitched our tent and laid our blankets in a hole in a lava bespattered crag which was partially filled with the same glass-foam. This lava fountain seemed—as I found in the case of the 1868 outbreak afterwards—to have broken out at the intersection of two fissures, one leading to the top of the mountain and the other more or less at right angles to it. After our evening meal, I climbed over the rough lava a short distance to get a good view of the scene. It was unique. From the whole interior of the crater rose the great illuminated column of smoke, apparently about five hundred feet wide. The sight was grand and fascinating. Perhaps the circumstance which impressed me most was the dead silence which reigned. The noisy explosions of the night before had been left far behind. There was no wind, and the now illuminated smoke rose as it had done the day before in a well defined perpendicular column, but

spreading out on all sides at a great height in the atmosphere. I gazed at it long and steadily. I had toiled all day to get to this spot and to learn something, perchance, about volcanic action, but here at the crater, the only idea which I seemed capable of realizing, was my own utter insignificance amongst this waste of fire, smoke and lava, and as I turned from the view a moment to look back at the little white tent, tinged with a lurid red, perched amongst a chaos of black slags, I felt as an astronomer might, who, looking through his telescope at the surface of the moon should suddenly discover a habitation; the difference being that here I seemed to be in the moon, or at least in a spot which was equally unearthly and unsuited for human existence. The exertion of the last two days made my bed of pumice welcome, and after retiring I slept till daylight, not a single sound having disturbed us. On looking out in the morning, the great, steadily rising pillar of cloud beside us was reassuring. The color of the smoke, by daylight, seemed to be about the same as that of a steamer burning Welsh, or semi-bituminous coal after she first fires up. It rose gently, curling in great wreaths and folds, just as it might from the funnel of a huge steamer. I made an attempt to climb the edge of the crater and look in, but after scrambling for some time out of one sulphury crack into another, a thick fog crept up the mountain side and enveloped me, so that I could see nothing in any direction, and was glad, when on retreating, I found myself within hail of my guides, although I could neither see them nor the tent. In the course of an hour or two the fog cleared up, and we started down the mountain, our provisions and water being only sufficient for half a day longer. In descending, I kept as near as possible to the lava stream which was running from the lower part of the crater, in the usual covered passage formed by its own cooled crust. At the lower side of the crater, just where the slope became moderate, we observed some vitrified breakers. The molten glass-foam had run over the lip of the crater in great waves and now stood on the gentle slope below, like petrified combers on the sea shore. The likeness was the more remarkable because the break of the waves was up the slope, and the falling crests were in the opposite direction, mechanically speaking, to those of the ocean waves. Here, the motion of the upper and thinner portion of the glass-foam appeared to have been arrested as it ran down the slope, before that of the middle portion, by its more rapid cooling, That is to say, the massive, and therefore, more fluid part of the wave had flowed somewhat faster than the upper part—although the base showed that it had been retarded by friction—and so left the curl behind, or towards the rise of the slope, as it appears in the waves breaking on the shore. In some places the wave seemed to have bent, fallen and doubled upon itself, and the vesicular glass had solidified in great folds of a delicate green shade, looking like the folds of satin as they are sometimes displayed in a shop window. The material of the waves seemed to be identical in composition and colour, with the usual Hawaiian

pumice, or glass-foam, and the semi-transparent glaze covered the whole outer surface.

We had made a considerable detour on our way back to the camping ground where we had left our party, but saw nothing worthy of special note along the flow, except that we happened to be close by when a side stream of hot lava ran over a cave, and an explosion of heated air took place—water in this region was out of the question. We got belated, and were compelled to go supperless to rest on the ropy *pahoehoe*, which, with nothing but a blanket to interpose, was not so comfortable to lie upon as the pumice at the crater. It was, however, better than *a-a*, and rising early next morning, we arrived at the camping ground just in time to hail the native, who was leaving with our horses, and who had been instructed to wait for us; the rest of the party having left for Kailua the day before. We could hardly have blamed him for leaving us to get to the coast as best we could. He had concluded that we were *make*, (dead.) Few Hawaiians could have been found to remain a night alone amidst the fires and thunders of their offended goddess *Pele*.

The immense columns of smoke which so constantly rise from the orifices of eruption on Hawaii, may often be largely composed of the vapor of water. When the lava breaks away, great red-hot chasms must often be left, and percolating surface water may well find its way into them and escape at the only opening, that is where the lava escapes. At the time of my visit to the 1859 crater, the top of the mountain was covered with snow, which would be one source of percolating water. Sulphurous fumes seem always to accompany this smoke, as indeed seems to be the case whenever red-hot iron and water are brought into contact, but in these lava eruptions, leaving and producing great white-hot fissures, the quantities of water and iron-lavas which come in contact with each other must often be very large. When we remember what a great column of smoke a wagon-load of damp straw, set on fire, will produce, we seem to have in the surface water which may percolate into the heated caverns, an abundant source of vapor or smoke. One important ingredient in most Hawaiian volcanic smoke so-called, is the excessively light, glassy threads, films and vesicles, which the heated air first forms, and then raises to a great height in the atmosphere. It is well known that in a very large fire, the violent up-currents of heated air, will carry up even charred beams of timber, finally depositing them at a great distance. At some of the Hawaiian eruptions, particularly in the summit crater, the quantity of heat and heated air must be greater than at any fire, and must carry up to enormous heights, the *Pele's* hair, pumice and glassy fibres and vesicles of all kinds.

The next time I visited this river of molten stone was some months afterwards, at the sea-shore at Wainanalii, where it had never ceased running into the sea from the date of its first arrival there—early in January, 1859. I happened to be at the port of Kawaihae, eight miles

off, in the barkentine Jennie Ford, which was about to load cattle for Victoria, V. I. We had seen the steam rising at the shore all day, and in the evening the master manned a boat and pulled to the scene. The red-hot molten lava was quietly tumbling into the sea over a low ledge, perhaps six to eight feet high, and five to six hundred feet long. The lava did not seem to be quite so liquid, or of such a bright color as it did when it ran out of openings in the side-wall of the *a-a* stream up in the mountain some months before. It ran more like porridge in great, flattened spheroids, which were sometimes partially united together, and sometimes almost separate. The cooling was to be expected after its long journey down the mountain. There was no steam to be seen escaping from the lava, and it was not until after each spheroidal mass had disappeared for a second or two under water that puffs of steam came to the surface. The general effect, however, was an apparent steady rise of steam along the whole line. It was a cataract of molten stone.

It has sometimes occurred to me that this tendency to form great spheroids in the molten state may be in part the origin of basaltic columns, and which semi-fluid spheroids under the united and successive effects of compression, cooling and contraction tend to take a six-sided columnar form. The same principle may be applicable in accounting for the great weathered spheroidal masses to be seen in ancient lava streams, and which break up under the decomposing influence of the atmosphere in concentric coats like an onion. We experienced no discomfort whatever when we rowed within a few yards of the molten cataract, except from the heat; there were no gases but the rising steam, and nothing was thrown up. As the great, flattened spheroids rolled quietly over into the sea, a slight commotion only was caused in the water. When the men lay on their oars, close in, we found the boat was set rather rapidly outward. The surface water was of course quite warm. Here was a current experiment for Dr. Carpenter on a large scale. The water was heated, rose and flowed outwards over the surface, whilst the cold water below supplied its place slowly in mass. After watching the sight for some hours, we landed and slept in a native grass house, which had been left on a very slight rise between two streams of this flow. This effect I have seen in many places about Hawaii. The slightest change of level on a general gentle slope may divert the biggest lava stream, and under the same circumstances any artificial obstruction, or an artificial encouragement to it to flow either way, *may* be effectual. This may often be of great practical value, although it need hardly be said that a rapid and confined lava stream will sweep whole hills before it, or it will sometimes get under acres of ground and float it off. There is no doubt, also, that it will often force itself uphill by the hydraulic pressure acting in the pipe formed by its own cool crust. I may mention here that, amongst its other vagaries, it will sometimes spread itself out in a tongue of lava on the surface of a pool of water. As

one set of tongues harden and are followed up by a slow flow from behind others are formed, and the lava will sometimes cross a small, but deep, stream, and when the water lowers it leaves a natural bridge that can be walked over. Mr. Furneaux has a painting of one said to be formed in this way. I have seen the lava tongues in the act of making out on the surface of a pool at the flow of 1880–81, near Hilo.

In the morning, after sleeping in the grass hut at Wainanalii, we walked on the crust over the top of the lava stream, which was pouring in a steady cataract into the ocean. The surface was composed of smooth pahoehoe not rough a-a, and it was impossible to tell where the molten stream underneath us was, except from the increasing heat, which however was not so great as to prevent our walking everywhere. From different positions this day we could see a large portion of the course of this flow, and right up to the source; but not a suspicion of steam, smoke or gases appeared at the crater or anywhere except at the sea where the sea-water was being evaporated. The molten stream was simply running over, and it continued to do this steadily in great volume, and without intermission for five months after my visit to the crater.

A year or more after this, when all was cold, I paid a final visit to the 1859 crater, but from the opposite direction, and we had to force our way over the horrid lava desert between the three volcanoes, Mauna Loa, Mauna Kea and Hualalai, where not a blade of vegetation is to be seen, or a drop of water to be found. Our feet had to be protected by raw-hide sandals to prevent our boots being cut to pieces by the glass-like crystals of olivine. It is a wilderness of a-a streams with oases of pahoehoe.

We started from the side of Mauna Kea before noon, with two natives and a donkey to carry our tent, blankets, water and provisions. Before we had got far into the a-a our guide confessed that he had lost the almost imperceptible goat-hunters' trail which alone rendered the way practicable, even for an animal with hoofs like steel, which all those brought up on these "clinkers" seem to acquire. The poor animal was continually getting its legs jammed amongst the blocks of sharp pointed a-a, and there was no resource but to unload it. The two men, however, divided the load between them and continued the journey, skipping from one shaky block to another as fast as I could do without any load to carry. It was well on in the afternoon when we arrived at a little creek of pahoehoe amongst the a-a, with the 1859 crater just perceptible far up the mountain. The guide lifted the demijohn of water—which we had drawn upon heavily—and shook it. He looked at the crater in the distance, then at me. He was a conscientious native, and knowing that the delay was through his own fault, he at once offered to return with his comrade for a new supply of water, and as he had now found the trail, he assured me that they could be back early enough next day to reach the crater of 1859 before dark.

I gladly availed myself of his offer, and after pitching the tent and taking a few mouthfuls of *paiai*, or pounded baked taro mixed with water, the men started back in a sort of ambling gait, which along the trail they had now found, might have covered five miles an hour. I wandered about amongst the narrow creeks and bays of pahoehoe, which wound about like a labyrinth between great walls of the horrid a-a, sometimes getting into a *cul-de-sac*. Nowhere was there to be seen a blade of vegetation. The trade-wind clouds are mostly condensed on the windward slope of the table land between the three volcanoes, so that here all is dry, and hardly any decomposition whatever has taken place on the surfaces of the lava streams which have flowed mainly from Mauna Loa. In one place an a-a stream had made a rush at another and had partly pushed it on one side, or mounted over it, or thrust it up into great slaggy peaks; so that the scene gave one the idea of chaos after an earthquake.

The general prospect all round was desolate and strange, and when night came on I found myself sitting before the opening of my tent, staring at the jagged outline of the black a-a wall in front of me, which was dimly visible against the leaden sky. I required no lamp or candle—which indeed I had not brought—and a fire was out of the question. Although no "curfew tolled the knell of parting day," and no "lowing herds wind slowly o'er the lea," I felt very much indeed as if my guides and the sun had "left the world to darkness and to me." The exercise of the day and the cool mountain air soon made me creep under my blankets to rest, and the sun was shining brightly into the black hollow when I awoke next morning. By 10 o'clock A. M. my guides appeared with a fresh supply of water, and we were soon on our way rejoicing. We reached the 1859 crater two hours before dark, the way being mostly over pahoehoe. I started at once to explore, and found the interior to be like an immense pie, of which the crust—the surface of the former lava lake—had been broken in all over, whilst glass-foam, or so-called pumice, filled up all the holes and hollows between the broken-in crust, and represented the contents of the pie. I attempted to cross it, but when I walked over the loose pumice it seemed to slide off into unknown depths, and it was impossible to keep entirely on the highly-inclined pieces of crust. I observed at the upper edge of the crater a small cone higher than the rest, so I gave up the attempt to cross the centre and walked round to the cone. I found it to be the mouth of a chimney, perhaps 15 to 20 feet wide, in which all was dark. There was a narrow ledge inside the rim on to which I descended, with the object of looking down the hole, but all was the blackness of darkness, as the side of the interior retreated, and there was nothing to reflect the light. I looked round for a stone to throw in by which to estimate the depth, but only found a piece of scoria; I threw it well into the middle of the blackness, but in the excitement of the moment I forgot to count. After waiting what seemed to me an unreasonable time for a sound, and hearing nothing,

I began to feel a sensation that I had read of, but never believed in, as if I should have to jump in after the stone. I thought it time, therefore, to climb up off the narrow ledge on which I was standing, and change the subject by surveying the great, broken-up glassy crust of the lava lake from which the molten lava had flowed away.

Mr. Vaudrey, an English traveler, was on the mountain when the eruption broke out on this spot, and hastened to it with his guides. He got as close as the heat would let him, and described it to me as a simple fountain of white-hot molten stone, hundreds of feet high and wide, the fall of which made a continual dull roar, and caused the ground to tremble beneath him.

My visit to the dead crater produced feelings akin to regret, and the next morning I was in no humor to make further explorations, more especially as our food and water were exhausted; so "we folded our tent like the Arab and silently stole away." All regrets were quickly dispersed as we walked briskly down the gentle slope, with the fresh trade wind in our faces; whilst right before us—as it were hanging in space—were the elegantly outlined summit cones of Mauna Kea covered with pure white snow, just pink-tinged by the rays of the morning sun; the whole mountain being set in a bright blue background of sea and sky, which seemed—from our elevated point of view—to blend together at about half its altitude.

Almost every great eruption on the sides of Mauna Loa has been preceded by a small eruption of lava, or several on, or close, to the top of the mountain. The lava column has thus shown itself to be near its highest level, and therefore ready to break away. A crack, usually an old fissure running straight down the mountain, allows the molten lava to escape at different heights along it, but where a permanent cross fissure and fault intersects it, there will probably occur the grand fountain and main outbreak. I feel satisfied that this was the case at the great 1859 and 1868 eruptions, and probably also at the Kealakekua outburst in 1877. This mode of operation has sometimes given rise to a misconception. For instance the Hilo people point to a considerable crateriform hill, thirty miles off, or more, and which is clearly to be seen at that distance, on Mauna Loa, as the origin of the great flow of 1880. Captain Dutton, however, who approached the source from the other side of the mountain, arrived at a spot on the same line of crack, where the lava seemed to have also flowed out. This was in one sense the origin, that is, it was probably the first or the highest outflow, and here Captain Dutton says, there was no appearance of a crater. The same thing occurred in the 1868 flow at Kau. The grand eruption took place near the escarpment and fault just above the Government road, and running nearly east and west, and where it is intersected by another escarpment and fault running nearly north and south, or up and down the mountain. But lava ran out in the same line above it at different places all the way up the mountain; and also a short distance above the main outflow it may still be seen as it appeared to have been

squeezed out of the crack, and without any appearance of a crater. The pressure of the gradually rising column of lava—when the sides of the mountain retain it—often bursts through the bottom of the summit crater of Mauna Loa, and sometimes rises in fissures at the very top of the mountain before it escapes at a lower level. Often indeed, as we elswhere observe, the eruptions at the top of the mountain are not followed by any visible escape of the lava at a lower level. Several cases, however, having occurred of eruptions at a short distance from the coast and in the sea, renders it probable that the latter may be often the way the column relieves itself without the effects being visible. The history of the mountain for the last sixty-four years shows that the surface of the lava has stood almost continually near the top of Mauna Loa; and a large number of eruptions since 1843 have broken out between the top of the mountain and a height of about 10,000 feet. It would seem that this central column of lava is like the Kilauea column, a steadily rising one, and that when it reaches a certain height the liquid, under the increased head of hydrostatic pressure, relieves itself, generally at a permanent fissure down the side of the mountain, and most copiously at the intersection of a second fissure.

Nothing will persuade some of the Kau people that the eruption of 1868 did not draw off the lava from Kilauea crater, forty miles distant, the level of which certainly fell after the 1868 eruption occurred. It was said that by putting the ear to the ground, the noise of the flowing lava underneath could be distinctly heard. It may have happened that this outbreak lowered the great central conduit of Mauna Loa and that of Kilauea also, as it was situated at the intersection of two permanent fissures, one of which runs to the top of the mountain, and one in the direction of Kilauea. Two columns of liquid of different densities, and standing at different heights, may thus be simultaneously lowered by passages connecting both, and still without affecting their height relative to each other, as long as the difference of density, or of the nature of the connecting passages, or both, counterbalanced the difference of the heights.

The lava which came out at the crack above the main outburst of 1868, deserves particular notice, as a great deal of it seems to be a mass of lava froth. It flowed nine or ten feet deep amongst the small trees which stood in its path, and was to be seen shortly afterwards left amongst the branches and wrapped round the stems, at about that height, whilst the main body of it had flowed off, and the vesicular crust had fallen down. Many of the trees were entirely destroyed, but many others in the wake of this flow of lava froth, were only charred on the outside, and although some of them were only seven or eight inches in diameter, they were not borne down by the weight of the stream. The whole evidence here on the spot, seems to show clearly that at this part of the flow, the lava was comparatively cool and very

light; just such an effect, in fine, as a thorough mixture with the external air might produce. The substance, both on the ground and in the trees, seemed to be little more than what is called basaltic pumice, which had been in a molten and flowing state. It should be noted, however, that the greater portion of this flow below the fountain was compact lava, with much olivine, but at this part of the fissure, just above the fountain, an emission of froth only, seemed to have taken place. Emissions of lava froth have, however, been observed in many places on Hawaii. I have already noticed the overflow of it from the lip of the crater of 1859. Molten glass-foam may be running off above over the edge of the crater, while molten, compact olivine-basalt may be flowing from a lower opening in the crater or fissure.

The a-a flows of the 1868 eruption, which ran over the table land of Kahuku, presented a remarkable contrast, as they stood like great black railway embankments, clearly defined on the bright green grassy slope. Large crystals of olivine could be seen in this scoriacious a-a, as one rode past it, as thick as plums in a pudding. It was two of these streams, that diverging from one, passed around a native house erected on a slightly raised area, and met below, completely shutting in the inhabitants for some days.

There seem to be three classes of *pahoehoe*, all of which may be formed from the same lava; the different appearances arising mainly from the quantity that is released at once, and its heat and consequent fluidity. There is a kind that spreads over the surface of the ground in low bosses or tongues, and which was very plentiful in the flow near Hilo, in 1881. Then, there is that which spreads over the surface in large regular mounds, (*hornitos*,) most of them hollow, and which appear to arise from a more liberal supply of hot lava. I have before me a photograph of *pahoehoe* which ran out close to, or from the fountains of 1887, different from either of the above. It looks as if a running flood of very hot, and therefore fluid lava, had been instantly frozen in its course—as indeed, it no doubt was.

It is an impressive and weird sight to see a powerful black and red a-a stream, crashing in amongst the beautiful bright green ferns and foliage of a tropical forest, and obliterating it; but to see those creeping tongues of viscid *pahoehoe* slowly eating their way, with an amœboid-like movement, over mile after mile of a grassy slope, dotted with trees, is the "abomination of desolation." A tree will often be left standing, apparently unharmed, and in all its pride of beauty, in the midst of a sea of the ropy slag. But the heat near its roots will gradually char the trunk through, and at last we see it fall slowly and gracefully, all fresh and green, on to the glassy backs of the red-hot, crawling monsters around it. I have seen little birds—braving the heat—twittering and fluttering around such fallen trees. One wonders why nature should thus deliberately and ruthlessly destroy its own handiwork; the partially consoling reflection comes, that this volcanic protoplasm is, in fact, the "physical basis" of all the beau-

ties we see around us. On this group of islands, it not only forms the frame-work on which the plants and animals live, but contains—with the atmosphere—all the elements of the most fertile description of soil, which permits the growth of a luxuriant vegetation on which animal life subsists.

APPENDIX TO CHAPTER VI, SECTION 10, PAGE 192.

Letter from W. D. Alexander, Hawaiian Surveyor-General, on the Evidences of Upheaval on the Hawaiian Group:

HONOLULU, February 21, 1884.

HON. W. L. GREEN.

DEAR SIR:—In accordance with your suggestion, I have jotted down a few of the evidences of upheaval that I have observed during my surveys, chiefly on Oahu and West Molokai.

In the first place, it seems to me that the coast plains of Oahu, which, like the series of coast craters, are almost a distinctive feature of this island, were produced by upheaval, and are based on underlying coral reefs. This is certainly the case in the Honolulu district, and the coral formation crops out conspicuously in Paakea, north of Moiliili. The same is true of the region adjoining the Ewa lagoon, in particular the peninsula of Waipio and the lower part of Honouliuli, near Barber's Point, where the coral formation shows itself over an area of nine miles in length by one to one-and-half miles in width.

On the Waipio peninsula and the little islet of Laulaunui are banks of oyster shells several feet thick above high water mark. In the valley of Kalauao, on the east side of the lagoon, is a sort of water mark, a very distinct layer of water-worn pebbles about 20 feet above the present sea level, and horizontal in position, which has been cut through by the stream that has made the valley, and seems to be related to changes in the coast line.

In the Waianae district, at *Kahe*, I found a ledge of coral 79 feet above the level of the sea, and 730 feet distant from it. Coral reefs crop out at intervals all along the Waianae coast. South of Puu o Hulu there is a ledge of coral or sandstone 56 feet above sea level, and a quarter of a mile inland. In Lualualei we found an extensive plain of the same formation at an elevation of about 20 feet.

At the south-west end of the ridge called Mailiilii is a sandstone ledge 81 feet above the sea. In Keawaula we visited a famous cave in this stratum about 800 feet inland. Further north, and perhaps a mile south of Kaena Point, are ledges of coral or sandstone above the road at a considerable elevation.

In Waialua the narrow plains along the sea from Mokuleia to Waimea are evidently formed by the upheaval of the ancient coral reef. The well-known sandstone hill at Kahuku appears to be part of the former sea beach, deeply worn by the action of the waves. There are numerous sandstone hills between Kahuku and Laie, situated further inland, which are probably composed of blown sand, like those at Wailuku, Maui, and were formed at an ancient period before the up-

heaval. The long promontory at Laie, which is 50 feet high, is composed of coral and sandstone. This formation seems to be entirely wanting in the vicinity of Kaneohe Bay. The soundings off this coast rather point to a subsidence, perhaps earlier than the upheaval in question. In Waimanalo, quarter of a mile inland, are several hills of sandstone resembling those of the Kahuku region. I imagine that the ancient coast-line can be traced part way along the cliff east of Makapuu Point.

Between Koko Head and Diamond Head the ancient coral reef crops out, especially near Waialae in many places. The large fish pond at Maunalua, which is filling up, seems to have been once an arm of the sea. It is well known that pieces of coral and shells are found imbedded in the tufa of Mokapu, upper Koko and other coast craters, indicating that the volcanic forces which produced them broke through coral reefs. On Molokai we find the ancient reef 10 or 15 feet above the sea-level near Kaunakakai and half-way to Kamaloo. On the north-east side of West Molokoi are sandstone hills some 400 feet above the sea, which, however, may be explained as *blown sand*, gradually solidified by the action of rain-water. On the west coast, coral reefs and ledges of sandstone crop out above high water mark in several places, *e. g.* at Puhikaui, two or three miles north of the lighthouse, and at Kamakaipu, where the ship Carleton was wrecked. About five miles north of the lighthouse is a large sandhill, the lower part of which is hard, fine sandstone, partly undermined by the sea, and tumbling over in immense blocks. Beyond is a bay two or three miles wide, with a sandy beach, and inland a plain two miles long by half a mile wide, as level as a floor, and only a few feet above the sea level, which seems to indicate an upheaval.

At the north-west point, "Ka Lae-o-Ka-Ilio," the sandstone formation extends across that corner of the island. Sand is even now carried by the wind more than half-way across West Molokai—about midway between Mauna Loa and the north coast.

The appearance of the eastern end of Molokai would favor the theory of a subsidence rather than an upheaval.

On Lanai, on the north-east side near Maunalei, blown sand has been carried far inland and hardened into stone; but I see no proof of upheaval there or on the island of Maui.

I submit these brief memoranda for what they are worth, and remain as as ever, yours very truly,

(Signed) W. D. ALEXANDER.

APPENDIX TO CHAPTER VII., PAGE 217.

Is there a Scientific Basis for selecting any particular longitude for a Universal Prime Meridian?

The discussions at the different Conferences which have met with the object of establishing a universal prime meridian from which all nations may estimate longitude, indicate that no truly scientific basis

has been suggested for selecting any particular meridian for that purpose. If we could, however, fix the position mathematically of the central line of Guyot's great zone of fracture, and show at what meridian in Europe it becomes tangent to a parallel of latitude, this would perhaps offer a physical basis for fixing the zero of longitude. This would seem however to be impossible of accomplishment for many reasons. The fracture is, in the first place, probably beneath the Mediterranean Sea, and such a fracture, if it could be seen, would run for some distance so closely coincident with the parallel of latitude to which it was tangent that no particular meridian in its course could be selected as the exact tangent point. There are a number of considerations, however, which tend to show that the neighborhood of the tangent point in the northern hemisphere of this great astronomical fracture is also in the neighborhood of the point where a scientific prime meridian can alone be looked for. That is to say, the position of the central line of fracture; or, rather, the tangent point of the central line in the northern hemisphere, has been the physical cause of the following series of physiographic phenomena.

It has collected the continents—the habitable portions of the globe—around a point in the English Channel near the longitude of Greenwich and in about 50° north latitude, and therefore not far from London and Havre. That the continents are thus collected is admitted by all physical geographers, and this point is made the centre of their maps of the land hemisphere.

The tangent point of the same line of fracture to a parallel of latitude in the southern hemisphere is in the middle of the Pacific Ocean. This helps to make this ocean so large, and at the same time affords a good terminal meridian for our maps or charts—180° east or west of Greenwich—allowing it to pass along a wide expanse of ocean and through Behring's Straits, or through one of the two inhospitable peninsulas projecting from North America and northern Asia, which are just separated by Behring's Straits. The obliquity of the ecliptic and the zone of fracture parallel to the plane of the ecliptic thus appear as the physical causes why the middle and the ends of our maps of the world are usually placed where they are.

Prof. Guyot defined the central point or pole of the zone of fracture to be on the Arctic circle in the middle of Behring's Straits—say 169° west from Greenwich—and with a radius of 80°. This would bring the tangent point to a parallel of latitude in the northern hemisphere in about longitude 11° east from Greenwich, and 33½° north latitude. The pole of a fracture parallel to the plane of the ecliptic must be on the polar circles, and as the fracture is principally in the northern hemisphere, the arctic circle is the natural one to refer it to. We placed the tangent point of the great zone of fracture—before we had seen Prof. Guyot's map—in latitude 36° north and longitude 5° west of Greenwich. Any tangent point between 11° and 12° east and say 7° west of Greenwich, would answer as a roughly dividing line of the

northern and southern continents, and passing through the three intercontinental seas, but outside of these limits no good dividing line so passing, and parallel to the plane of the ecliptic could be drawn. We are thus, by this rule at least, confined within fixed limits of longitude in deciding on a prime meridian.

It is worthy of remark that this same zone of fracture thus passing through the Mediterranean, and producing that sea, has at the same time produced in connection with the polar circle fractures at right angles, the peculiar features of Europe, with its peninsulas pointing into the depression. As has been well shown by Guyot and other physical geographers, the early civilization of Europe is a result of this configuration. The present civilization of America is merely an offshoot from that of Europe. May we not then say that western civilization is due to the northwardly trend of the zone of fracture; for although the same zone produces analogous features in the other two intercontinental seas, these happen to be in tropical regions which have not proved favorable to the origination of the European type of civilization.

The tetrahedral collapse, the obliquity of the ecliptic and the zones of fracture parallel and at right angles to it, are thus in a very direct manner connected with the history of civilization.

As a subsidiary method of arriving at a close approximation of the tangent point of the zone of fracture in the northern hemisphere, we may perhaps make use of the remarkable arc of a small circle described by the volcanic line of the Aleutian Isles, which, as remarked in Chapter III., is parallel to the plane of the ecliptic. We shall find its centre or pole on the arctic circle and in say longitude 177° 30′ west of Greenwich. By using this point as the pole of the central line of the zone of fracture, with any suitable radius, we bring the tangent line to a parallel of latitude in the northern hemisphere on the meridian of 2° 50′ west of Greenwich, or close to the meridian of Paris. There would however be practically so little difference between this meridian and that of Greenwich as a zero, that the wish of the majority, as shown at the prime meridian Conference in the United States in 1884, would probably prevail. Scientific prime meridians, like scientific frontier lines, are apt to be decided by the strongest fleets or battalions.

It is truly a noteworthy circumstance to find that the meridian of Greenwich—or say the great port of London—is so nearly in the centre of the land hemisphere, and that its anti-meridian, 180° east or west makes a good finish to our maps, and we may add a good meridian for the change of time by vessels crossing it. It is thus an appropriate meridian to take as that on which the great zone of fracture in the northern hemisphere may be assumed to be tangent to a parallel of latitude; and for all these reasons combined, it presents itself as a suitable prime meridian for all nations. In all these respects Paris or Havre or Gibraltar, or other cities near the same longitude conform to the conditions equally well; but, as we go eastward or westward of

these limits we begin to lose the [illegible]

[illegible] southern continents, and passing through the three inter-

these limits, we begin to lose the advantages of a meridian which may be said to cut the great ecliptic fracture, where it becomes tangent to a parallel of latitude, and to depart from the central meridian of the land hemisphere, or of the habitable portion of the globe.

Let us here recapitulate the chain of physiographic events which have produced these results. First, the tetrahedral collapse of the earth's crust, produced the tilt or inclination of the earth's axis of rotation, which inclination decided the direction of the ruptures formed by the luni-solar tidal elongation, parallel and at right angles to the plane of the ecliptic; whilst the earth's rotation, acting differently on the generally upheaved areas to the northward of the ecliptic fracture, and on the great subsiding areas to the southward of it, collected the continents around Africa, thus forming the land and water hemispheres. It may be worth noting that on this hypothesis the pyramids of Egypt seem to be on one of the most stable and stationary areas of the earth's wrinkling, shifting crust; and on this ground a spot in their neighborhood might have a claim to be made the initial meridian for the universal and permanent marking of time and distance for all nations; for there is little doubt, as has often been suggested, that certain portions of the earth's crust—such for instance as the west coast of South America—may in the course of centuries change their longitude, or be thrust away from the subsiding bed of the ocean. Southern Spain and Portugal and the northern shores of West Africa, seem also to be an area of the earth's crust in this predicament, as the great physiographic events traceable in ancient, and actually noticed in recent times, indicate. There are no doubt equally unstable and, so to speak, critical areas in the two corresponding regions along the zone of fracture, that is, about the Carribean Sea and the Eastern Archipelago, where the two systems of fissures—polar circle and ecliptic—also cut each other at right angles.

APPENDIX TO PAGE 165.

Remarks on the Tabular Statement of Hawaiian Eruptions, with details and references showing the probable nature of the connection between the lavas of Kilauea and Mauna Loa.

Kilauea and Mauna Loa are taken to be separate volcanic mountains, as much so, in one sense, as any two great volcanic mountains on the group, for as we have remarked in Chap. VI., the calderas are some twenty miles apart, as all the others are, and they are on distinct pairs of main fissures.

Taking first the eleven great eruptions *and outflows* as per table, namely, those of 1823, 1832, 1840, 1843, 1852, 1855, 1859, 1868, 1877, 1880, 1887, we find that two eruptions, those of 1832 and 1868 were simultaneous in Kilauea and Mauna Loa, that is to say that a great subsidence of the lava in Kilauea, and which had previously been high in the crater, was coincident with great outbursts of lava on Mauna Loa.

In seven of the remaining nine cases of great outbursts of Mauna Loa, namely, those of 1843, 1852, 1855, 1859, 1877, 1880 and 1887, the lava

in Kilauea has been reported by competent observers as rising rapidly, or at least steadily, or as "active," "very active," or "intensively active" just before each Mauna Loa eruption, and as "showing no sympathy with Mauna Loa," or as "quiet," "comparatively quiet," "with little activity," or "profoundly asleep," immediately or shortly *after* each outburst from the flanks of Mauna Loa. The remaining two cases, those of 1823 and 1840, were subsidences in, and outflows from Kilauea, at a time when Mauna Loa was not in eruption either on the flanks or at the summit. Who then can say whether the concealed column of lava in Mauna Loa sympathized or not at these two periods, by *subsiding*? This would be the action to be expected, both from the general principles we have advanced and from the behavior of the lava in both mountains in nine out of eleven of the grand eruptions.

Outside of the above eleven great eruptions, we have eight eruptions to deal with, namely, one small outflow near the top of Mauna Loa in August, 1851, and which was evidently premonitory only of the Feb., 1852, flow on that mountain, and may therefore be disregarded. One eruption in the sea off Puna in 1844, our knowledge of which is too indefinite to count upon.

One small subsidence in Kilauea in 1886, when no lava broke out above the surface, and in which case it only took nine months for the lavas to return to nearly their normal height as they were before their subsidence.

The remaining five eruptions were confined to the summit crater on Mauna Loa, with no outflow on the flanks, namely, in 1865, 1872, 1873, 1875, and May 1, 1880.

This class of eruptions does not necessarily relieve anything in a hydrostatic point of view, although the eruptions in the summit crater may relieve the Mauna Loa column of lava of both heat and gases; but a reduction of both of these would have no effect on the weight of the column, for when a thick crust of cooled lavas had accumulated in the bottom of the crater it might soon press with nearly its whole weight on the molten lava beneath it.

These three summit crater eruptions, it will be observed, (calling the 1872, 1873 and 1875 fountains, one continuous eruption) did not occur till four years, four years and three years respectively after a previous great outbreak and discharge, whether on Mauna Loa or Kilauea. If there had been one single instance in this whole series of nineteen eruptions in sixty-four years, where either a summit crater eruption or an outflow on Mauna Loa had occurred when the lavas in Kilauea were *low*, it would have weakened materially the theory of a fluid connection between them, but taking all the facts together as we show them, the fluid connection between the lavas of the two mountains seems to be as nearly demonstrated as the nature of the case will permit.

Let us look at the evidence a little more in detail. The earliest re-

corded eruption on Mauna Loa took place in 1832. "On the 20th of June, Mauna Loa commenced to eject lava from the summit on several sides, and continued three or four weeks, with such brilliancy as to be visible at Lahaina, more than a hundred miles distant." (Hawaiian Volcanoes, by W. T. Brigham, page 387.) "In June 1832, an eruption took place both from Kilauea and the summit crater of Mauna Loa." In September of 1832, when Rev. J. Goodrich visited Kilauéa, the eruption had taken place. The lavas which previously had increased so as to fill up to the black ledge and fifty feet above, had sunk down again nearly to the same depth, leaving, as usual, a boiling cauldron at the south end. The earthquake of January (June?) preceding had rent in twain the walls of the crater on the east side, from top to bottom, producing seams, from a few inches to several yards in width, from which the region between the two craters (Kilauea and the Old Crater) was deluged with lava. About half way up the precipice there was a vent a quarter of a mile in length, from which immense masses of lava boiled out directly under the hut occupied by Lord Byron's party. See *American Journal of Science*, XXV., 199, and quoted by Brigham, Hawaiian Volcanoes, p. 409. The next eruption on Mauna Loa was in 1843, three years after the last outflow on that mountain. We can find no particulars of the condition of Kilauea just previous to the 1843 outbreak on Mauna Loa, except that the crater had been gradually filling up in the usual manner. W. T. Brigham says however, (Hawaiian Volcanoes, page 388,) "Kilauea was visited by Mr. Abner Wilcox during this eruption, (1843) but it showed no signs of sympathy with the summit crater." In this case no doubt the "sympathy" expected was increased action, but if Mr. Wilcox's visit to Kilauea took place a short time after the outburst on Mauna Loa, the lava lakes in Kilauea might be expected to be lower and quieter than usual, if the two columns are connected.

The Rev. S. E. Bishop has called our attention to a circumstance connected with the artesian wells around Honolulu, which affords a good practical illustration of the hydrostatic principles involved in this kind of sympathy between columns of liquid connected with a general sub-crust sheet of the same; and although it exhibits nothing but what might have been anticipated, is more convincing and more easily remembered, than any hypothetical deduction from the laws affecting liquids. A Chinaman had leased a tract of land near Honolulu, not far from the sea, suitable for growing rice—all he lacked was more water for irrigation. He determined to bore a wide and deep artesian well. It was eminently successful. He got an "eruption" of water which flooded his premises. The sympathy shown by the neighboring wells, was a considerable lowering of the head of water in the stand pipes, and the owners of them hastened to the Chinaman begging him to control the outflow of water in his well, which he did. After this a law was passed obliging owners of artesian wells to control them so as to prevent a waste of the common supply of water.

It may occur to the reader that in this reference to the behavior of the neighboring artesian wells, we are illustrating the action of what we have assumed to be a universal liquid substratum in the case of volcanoes, by an instance where the liquid layer is admitted to be local. It is evident that a stratum of molten lava limited to an area beneath the crust about the Hawaiian group, for instance, might give certain results which we see in Kilauea and Mauna Loa, as well as, or even better than, a universal molten substratum. On the other hand, let us consider for a moment what might be the result in artesian wells derived from a general stratum of water connected together all round the globe. The effect of opening a very powerful well with an unusually large outflow, would still act more or less locally. That is to say, such a well sunk at Honolulu might first slightly lower the head of water of the wells immediately round it, although not so rapidly or in such a marked manner as if the water stratum was local only. The nearest wells outside the group, say in California, two thousand miles off, would, on the assumption of a universal layer of water, hardly be affected at all by the large outflow on the Hawaiian Islands, or if they were, the coincidence in the effect might be obscured by the action of the wells over the rest of the earth, as well as by the rainfall at the moment in different areas. Such an effect as this, is, in truth, what seems to occur at volcanic vents. As we shall see, the sympathy between even neighboring volcanoes is sometimes partially obscured, and although under certain circumstances more distant volcanoes in a range sympathize by being active together, such as those of Chile in 1835, or those of Java in 1884, the farther apart the volcanoes are, the less apparent is the sympathy in their action.

In looking for a sympathetic movement in the lavas at openings connected with a general molten substratum, we must always bear in mind that we are dealing with a liquid which is viscous and even viscid at still high temperatures, whilst it congeals at a temperature far above that at which water assumes the gaseous state at the ordinary pressure of the atmosphere. It should cause no surprise therefore, if in most cases lava does not exhibit as clearly as water the tendency to preserve one universal level. We have seen, however, as a matter of fact, that even water itself, although connected, does not always preserve one level. Bearing in mind then, how frequently a long row of volcanoes will sympathize in their eruptions, we may safely follow Charles Darwin in regarding volcanic phenomena taken together, as indicating "some slow, but in its effects great, change in the form of the fluid surface on which the land rests." (See ante, page 19.)

In August, 1851, a small outflow took place near the summit of Mauna Loa, lasting three or four days only, but in February, 1852, a grand outbreak and fire fountain broke out on the northeast side, when the lavas ran in a large stream for a month. Mr. Coan writes with reference to Kilauea, under date of July 30th, 1852, as follows: "I had visited Kilauea in March, and found the action in the crater

much increased. On this occasion the action was still more intense. The great dome, one mile and a half in circuit and several hundred feet high, has now lost its key-stone, and the massive arch has fallen in. The orifice on the summit is two hundred feet in diameter and through this orifice you look directly on the raging fire below. On one side, the dome is rent from the base to the summit, and through this fissure smoke and lava pass off from the boiling cauldron.

"This fiery lake, so long concealed by the ponderous dome, is gradually rising and lifting and rending the superincumbent strata of which the great dome is composed and threatening, at no distant day, to engulf the whole overhanging mass within its burning bowels. Aside from this increased action within the dome, no important changes have occurred in the crater for two years past." (*Siliman's Journal*, (U. S.,) vol, XVI., p. 46, quoted by Brigham, page 417.)

It will be observed that this visit was some four months after the Mauna Loa eruption of February, 1852, had ceased, and Mr. Coan then found that the massive key-stone of the arch over Halemaumau had fallen in since March. This seems to imply a certain amount of subsidence of the lavas after the February eruption on Mauna Loa, but they had now—the Mauna Loa eruption having ceased—commenced to rise again as usual, and in looking down through the opening he found the action of "the raging fire below," "still more intense." All this seems to be, at least, not inconsistent with the sub-crust connection which we have assumed to exist between the lava columns of Kilauea and Mauna Loa.

The next eruption of Mauna Loa was three years after the last, and was the largest up to this date. It broke out August 11th, 1855, at an elevation at first, of some 12,000 feet, and lasted thirteen months—until September, 1856. We have fortunately, some particular accounts from Mr. Coan of the condition of Kilauea both before and after this great outflow on Mauna Loa, and which are pretty fully quoted in W. T. Brigham's Hawaiian Volcanoes, pages 417 and 418, and to which we refer the reader. It will be seen that in January, 1854, "a gradual rising is going on in the floor of the crater." July 18th, 1855, Mr. Coan writes: "For months past this awful furnace has been brightening and glowing and raging and roaring with fearful intensity." * * "During the last week in May and the first in June, visitors and passing travelers reported a fiery girdle round the whole circumference of Kilauea along the base of her lofty walls—and so intense was the heat, so suffocating the gases, so fearful the hissings, so awful the surgings, and so startling the detonations, that horses wheeled and plunged with panic, and men retired from the old Kau and Hilo road, which, as you may recollect, lay near the upper precipice, and passed the great fissure at a respectful distance." In August succeeding, the Mauna Loa eruption of 1855 broke out.

Under date of October 22d, 1856, Mr. Coan writes: "During the

whole of the past year *Lua Pele* has been getting more and more profoundly asleep."

Here again, we observe the kind of sympathy between the two mountains which we ought to expect. Before the outflow of lava on Mauna Loa, and three years after a previous one, the lavas in Kilauea have risen and show unprecedented activity. The lava then breaks out high up on Mauna Loa and runs steadily from it for thirteen months, whilst during just that period, Kilauea, Mr. Coan tells us, "has been getting more and more profoundly asleep."

The next eruption of Mauna Loa was four years after the last, and broke out Jan. 3d, 1859. The only special notice we can find of the condition of Kilauea at this time is in Brigham's Hawaiian Volcanoes, page 418. He says: "During the eruption of Mauna Loa, Kilauea was visited to see if any extraordinary action was visible, but it was comparatively quiet. The fires showed no sympathy with those being poured out 10,000 feet above."

This comparative quiet, however, of the lavas in Kilauea *after* an outflow on Mauna Loa, or after the first grand rush is over, is just the kind of sympathy we ought to expect, and which has, in point of fact, been nearly always exhibited.

This eruption of 1859, on Mauna Loa, is the one which we have described more in detail in other parts of this volume (see pp. 80, 163) and which we visited whilst in action at the main outflow, on the flat between the three mountains, in the middle of its course, and also where it poured into the sea at Wainanalii; whilst we also examined the flow at all these different points months afterwards when all was cold. We may observe here, that this and all the Mauna Loa outflows discharged the main mass of the lava, or at any rate a vastly greater proportion in equal times, during the first few days or weeks of the eruption, and at the locality of the main outflow, which is usually situated lower down the mountain than that of the first outbreak. In other words, a very large proportion of the whole flow is discharged whilst the reservoir is emptying under a high head of liquid. After this, the flows either cease altogether, or quietly "run over," which they often do for many months. This steady, moderate outpour for long periods, may in truth, represent merely the steady rise of the lavas in the main conduits, but it being discharged as fast as it rises, keeps the level about the same. This would explain on the hypothesis of a deep-seated connection between the conduits of the two mountains, why the lavas in Kilauea during this phase of the Mauna Loa eruptions, although generally to be seen, are described as quiet, inactive, profoundly asleep, and by similar expressions, amongst which we may include that of "no sympathy shown with the eruption on Mauna Loa."

As far as the known records go, nothing occurred either in Kilauea or on Mauna Loa—if we except the usual steady rise of the lavas in

Kilauea—until six years after the 1859 eruption. "On the 30th December, 1865, a light was discovered on the summit of Mauna Loa, which rapidly increased in brilliancy, and the whole upper region of the mountain was bathed in light. The action was wholly confined to the terminal crater of Mokuaweoweo, and although it continued for four months, no lateral outbreak took place." * * "It is most remarkable that no lateral streams escaped, and it is probable that the crater has been more or less filled, as is the case in Kilauea when no stream escapes from the encircling walls."

"*No sympathy was exhibited in Kilauea, and although the fires seemed constantly increasing for the last two years, no extraordinary developments took place until some weeks after the summit crater had become extinct.*" The italics are ours. The above quotations are from Brigham's Hawaiian Volcanoes, page 403. Here again Kilauea really exhibited just the sympathy with Mauna Loa which we should expect. The lava columns in both mountains had been steadily rising for years; the sides of Mauna Loa hold firm, but the lavas of this column burst through the bottom of the summit crater. Why should Kilauea sympathise any further than it did, for there was no relief of the weight of the column in Mauna Loa by an outflow on its flanks, although some slight relief of pressure might be afforded by the breaking through of the bottom of the crater of Mokuaweoweo. By May, 1866, (see Brigham, page 427,) when the summit crater eruption had ceased, Kilauea commenced a series of discharges all over the surface of the crater which was still in operation in August, (the date of Mr. Brigham's visit.) "New lakes of fire opened along the curve northwest to north of the great lake of *Lua Pele*, flooding all that portion of the crater with fresh lava, and reaching even to the sulphur banks on the southern side of the plain, in a stream about four miles long and from an eighth to half of a mile wide, cutting off, for much of this time the usual entrance to the crater. This whole portion of Kilauea now flooded was about fifty feet below the central area, it is now at least a hundred feet higher than it was last year, but the central plateau has also risen, and the relative height is about the same. The whole appearance of the crater has however, changed. The ledge of compact broken lava, which swept around the eastern end of the crater, marking the limits of Dana's Black Ledge, is nearly covered with the successive overflowings, and the caves which formed so interesting a feature of this portion of the crater are filled and obliterated."

Here again, it is evident that the lava columns in the two mountains have been rising steadily together. The cessation of apparent action in the summit crater of Mauna Loa may merely mean, that the immense mass of lava discharged in four months over the bottom of the crater of Mokuaweoweo had finally cooled and sealed up the opening, forcing perhaps, the rising lavas through lateral fissures, which however, may have been still enabled to resist an outflow on the flanks. But the gradual rise of the lavas in Kilauea keeps on, and

presumably also, those in the Mauna Loa conduit, until at last, nine years after the last outflow—the full period—the great outburst of 1868 takes place, and both mountains are rent from their summits nearly to the sea, and the lavas gush out simultaneously along both fissures.

These two great simultaneous eruptions were thoroughly examined by competent observers, and their observations have been recorded, full particulars of which may be found in the appendix to Jarves' History of the Hawaiian Islands, Honolulu, 1872, by H. M. Whitney, also in a separate notice by W. T. Brigham, published in Boston, 1869, and to all which the reader is referred. These accounts however, excellent and correct as they seem to be, require some care in order to condense the material points into a connected story. This we now attempt, mainly from Mr. H. M. Whitney's account in the *Pacific Commercial Advertiser* of May 9th, 1868:

"ERUPTION OF APRIL, 1868."

"The first symptoms of any unusual commotion on Mauna Loa were noticed on the morning of March 27th, about 5½ o'clock, when from the whaleships at anchor in Kawaihae harbor, a dense column of smoke was observed to rise in one massive pillar to the height of several miles, accompanied with a bright reflection, showing that fire existed in the great crater of Mokuaweoweo. In a few hours this pillar cloud dispersed and passed off, and no light was seen on the following night.

"At about 10 A. M. on the 28th, a series of earthquakes began, which continued at intervals with varied severity for over a month. At Kona as many as fifty or sixty distinct shocks were felt in one day, at Kau over *three hundred* in the same time, and near the great crater of Kilauea, the earth is represented as having been in a constant quiver for days together, with frequent vigorous shocks that would send crockery, chairs, lamps, etc., spinning around in a not very pleasant way. Mr. J. Porter, the proprietor of the "Volcano House," says he endured this for several days, as long as he could, till one night about 11 o'clock *Pele* sent one of Rodman's twenty-inch shot, with a well-directed aim, that struck the ground directly under his bed, when he jumped and ran, where or how he hardly knew, but he found himself after a while in the woods safe and sound.

"One can readily imagine the state of nervous excitement produced by the continual swaying of the ground, with an occasional shock like that produced by a heavy rock striking the crust beneath him. A lady, who spent two weeks in this shaky region, says that she put her ear to the earth during one of these "ground swells," and could distinctly hear the rushing and roaring of the lava waves beneath the surface, like the surging of waves in a storm. It was such a scene as unstrung the firmest nerves. Residents of Kau inform us that over *two thousand* distinct shocks occurred there between the 28th of March and the 11th of April, averaging over one hundred and forty a day for two weeks.

"The earthquakes continued to increase in severity from March 28th till April 2d, when about four o'clock in the afternoon one took place which shook down every stone wall, and nearly every stone, frame and thatch house throughout Kau, and did more or less damage in every part of Hawaii, while it was felt very sensibly on Maui, Molokai, Oahu and Kauai, the latter island 300 miles distant from the crater. Every church in the district named was destroyed, with perhaps a single exception. The shock was so severe that it threw persons from their feet, and even horses and other animals were served in the same way. A gentleman riding on horseback in Kau found his horse lying flat under him before he could think of the cause. The effect of the shock was *instantaneous*. Before a person could think, he found himself prostrate on the ground. The large stone church at Waiohinu went down in the same way—a sudden jerk, the walls crumbled in and the roof fell flat—all the work of ten seconds. Judge Lyman describes this shock as follows: 'Thursday (April 2d), between 4 and 5 P. M., we experienced the *most fearful of earthquakes* ! First the earth swayed to and fro north and south, then east and west, round and round, then up and down and in every imaginable direction for several minutes, everything crashing around us; the trees thrashing about as if torn by a mighty rushing wind. It was impossible to stand; we had to sit on the ground, bracing with hands and feet to keep from rolling over.' It left nothing but desolation and ruin throughout the district.

"Respecting the course or direction of the shocks, we have made many enquiries. Those felt here on Oahu have mostly been undulating, with a wave-like motion. On Hawaii they had three distinct characteristics—the *undulating*, with the motion generally from the northwest to southeast—second, the sudden short, sharp, *jerking shock*, occupying hardly two seconds—and third, a *thumping*, like a boulder or rock thrown suddenly against the crust of earth beneath you, and as suddenly falling down. Each kind was frequently accompanied by a *rattling noise*, like distant thunder or artillery, more or less distinct. The lighter shocks generally had no accompanying noise. We experienced one of these "thumping" shocks, while asleep near the crater on the night of the 10th. It sounded precisely as if a cannon ball had struck the floor under us, and then rolted along the veranda. It started us out of a sound sleep. At Kau the motion was often from south to north.

"Simultaneously with the heavy earthquake on the afternoon of April 2d, occurred the mud eruption at Kapapala, which is so singular and so unlike anything that has heretofore occurred on the islands, that we give a minute description of it. Kapapala is the residence of Mr. Chas. Richardson in Kau, about fifteen miles from Kilauea crater, and twenty-five from Waiohinu. About midway between Mr. R.'s residence and that of Judge Lyman at Keaiwa, six miles west, are two beautiful valleys, that extend from the road a couple of miles, which

every observing traveler must have noticed. They were studded with groves of *kukui* and other trees, and covered with a rich carpet of the softest *manienie* grass. Herds of sleek cattle were constantly browsing or enjoying the shade of the cool groves. Native huts were scattered here and there, and horsemen were frequently seen crossing the valley.

"This was the scene of the 'mud flow.' Just at the instant the earthquake occurred, the sides of the valley were rent, and from the fissure burst out, with a terrific explosion, a stream of red mud and water, which was driven by the explosion a distance of fully three miles. This stream was ejected simultaneously with the heavy earthquake, from both sides of the valley. Immediately under and near the fissures are heaps of stones and boulders, which were evidently thrown out first, and beyond these a vacant space, in which a native thatch house was left standing and the inmates left unharmed, while the mud and stones flew over and around them. Eighteen hundred feet from the opening the pile of mud commences, and extends a distance of three miles, varying in width from half a mile to one mile, and from two feet at the outer edges to twenty and thirty feet deep in the centre. Where it crosses the road it is thirty feet deep and half a mile across.

"This mass of mud was thrown out in less than two minutes, as if discharged from two huge batteries of ten thousand twenty-inch Rodman guns, planted on each side of the valley. At its further extremity is a pile of large boulders and stones, that appear to have been driven before the powerful explosion. As it swept through the valley it destroyed men, animals and trees alike. Thirty-one lives were lost, and between five hundred and a thousand head of cattle, horses, goats and sheep, some of which were just at the moment being driven across the valley to the farm house.

"This mud, or now more properly dirt, as it has become dry, consists of finely pulverized red soil, such as is so often found in the group. In some places it is mixed with stones, trunks of trees, fern leavs, etc. Trunks of trees are found standing, with their tops shot off by the explosion. 'The force with which these streams were ejected from the hills (says a writer in the *Gazette*) and the speed with which they flowed, is said by eye-witnesses to have been at the rate at least of a mile a minute. The rapidity was so great, even at the very extremity of the flow, that numbers of goats which were fleeing for life were overtaken by it, and found a short time afterwards by Mr. Richardson sticking by their hind legs in the mud.'

"Out of the hole where the mud was exploded, now issues a stream of clear, cool mountain water, which it is hoped will continue to flow, as it is the only stream in the district. It will be all the more acceptable as all Mr. Richardson's cisterns have been totally destroyed by the same earthquake which produced the rivulet.

"Some of the natives present at this eruption state that the mud thrown out was cold, others that it was hot, and that steam and smoke

issued from the rent after the eruption. It is quite probable that the earthquake created a subterranean rent, which brought this confined body of water in contact with the lava fires below, and thus produced the explosion, without heating the mass above.

"Mr. Richardson's loss in cattle, horses, cisterns and houses has been estimated at fifteen thousand dollars, which is probably the largest sustained by any one party. In the valley adjoining there was also a small land slide, but not on the scale noticed above. The soil thrown out is rich, and will soon be covered with dense vegetation, especially should the fine stream remain permanent."

We would say here, that this so-called explosion of mud has been regarded by most observers of the district since, as a land slide, the damp loose soil and trees which were on steeply sloping ground on the top of a still steeper rise, were shot off into the plain below by the tremendous earthquake jerking blow of April 2d.

Mr. Whitney next describes the earthquake wave which immediately followed the same earthquake. The point of most interest in connection with our present subject is contained in the following paragraph in a communication from Mr. Fornander to the *Hawaiian Gazette*, and which indicates that an outflow of lava took place at this time beneath the sea :

"At Punaluu, at the moment of the shock, it seemed as if an immense quantity of lava had been discharged into the sea some distance from the shore, for almost instantly a terrible commotion arose, the water boiling and tossing furiously. Shortly afterwards, a tremendous wave was sweeping up on the shore, and when it receded, there was nothing left of Punaluu! Every house, the big stone church, even the cocoanut trees—all but two—were washed away. The number of lives lost is not yet ascertained. All who were out fishing at the time perished, and many of those ashore. A big chasm opened, running from the sea up into the mountain, down which it is said lava, mud, trees, ferns and rocks were rushing out into the sea.

"The same wave that swept away Punaluu, also destroyed the villages of Ninole, Kawaa and Honuapo. Not a house remains to mark the site of these places, except at Honuapo, where a small "hale halawai," on the brow of the hill, above the village, stood on Friday last. The large cocoanut grove at Honuapo, was washed away, as well as that at Punaluu. A part of the big pali at Honuapo, on the road to Waiohinu, had tumbled into the sea, and people coming from thence are now obliged to take the mountain road through Hilea-uka."

THE LAVA FLOW OF APRIL 7TH.

"A company of eight or ten, including the writer, took passage in the steamer for Kona on the 6th of April, and arrived at Kahuku on the 10th, three days after the eruption broke out. We consequently had the finest opportunity that could possibly have been sought for seeing what proved to be a brilliant display.

"On the passage to Hawaii in the steamer, on the night of the 7th, the whole Island of Hawaii was seen brilliantly illuminated, the overhanging clouds reflecting the glare of the fires beneath, and a stream of lava was seen from the vessel, a distance of at least one hundred miles.

"We left Kealakekua Bay on the morning of the 9th of April, and after a slow, tedious ride of twenty-seven miles, over lava clinkers, reached Kapua towards night, where we slept in a thatch house, built by Mr. Chas. N. Spencer as an accommodation house, it being just half way between the bay and Waiohinu, and distant from the lava flow about thirteen miles. During the night we could hear the distant noise of the eruption—a peculiar rumbling, so different from the roar of the sea or any other noise, that, to wake up in the night and listen to its unaccountable utterances, tended to create fear with those who for the first time heard it. In the morning, several of the party decided to turn back to Kealakekua, and returned without seeing the grand sight before us. The others, seven in number, not counting native attendants, mounted horses and proceeded on to the flow.

"As we approached it the rumbling noise became more and more distinct, and the evidences of approach to some great disturbance of nature more frequent. The ground was covered with what appeared to be cinders, but on examining them we found they were fragments of pumice-stone, which had been carried by the wind a distance of over ten miles. Mixed with these cinders was *Pele's Hair*, which we found floating in the air, and when it was thick we had to hold our handkerchiefs to our nostrils to prevent inhaling it. Our clothes were frequently covered with it. On reaching an eminence five miles from the stream, we found a group of forty or fifty natives, who were waiting to cross over to Kau, and had been here several days. From this point dense clouds of smoke could be seen rising all along the course of the lava stream, from the mountain side to the sea.

"We hurried on and reached the flow shortly after noon, where from a ridge to the west of it, the whole scene opened before us. Between us and the crater was a valley five hundred yards wide and ten miles long, which had recently been overflowed throughout its entire width and length from the mountain to the sea, where it widened to two or three miles. The lava was of the smooth *pahoehoe* variety, from ten to twenty feet deep, and partially cooled over, though flames, smoke and gas escaped from numerous crevices. We stood on it, though it was hot enough to burn the soles of our shoes. This lava stream originated some ten miles up the mountain, and came down early on the morning of the 7th. It had ceased flowing, the eruption having opened a vent lower down and further south.

"Beyond this valley, about a quarter of a mile distant, was the pali of Mamalu, a steep precipice, which runs from the mountain to the south point of Hawaii, and forms the west boundary of the table land

of Kahuku, a beautiful level plateau, covered with tall grass, affording excellent pasturage for herds of cattle, horses, sheep and goats. About a mile above the road were the farm houses of Capt. Robt. Brown, who lived there with his family. Near by were the dairy establishment of C. N. Spencer, and other dwellings. This plateau was several miles in extent, running as far as Waiohinu, and sloping gently off to the sea, and dotted with hillocks."

We would observe that this plateau bounded by the pali or precipice of Mamalu—and which is clearly a fault of upheaval—has been raised up ages ago, and by that means kept comparatively free from lava streams which have flowed on each side of it. It forms therefore an oasis of rich pasture and sugar lands in a wilderness of lava streams. This precipice extending several miles back from the sea and leading towards the summit of the mountain is an important feature, inasmuch as it indicates the direction of the great fault and fissure from the sea to the top of the mountain, along which this eruption broke out. But to continue the story:

"On Tuesday afternoon, April 7th, at 5 o'clock, a new crater, several miles lower down than that referred to, and about two miles back of Captain Brown's residence, burst out. The lava stream commenced flowing down the beautiful grass-covered plateau, towards and around the farm house, and the inmates had barely time to escape with the clothes they had on, before the houses were all surrounded, burned and covered with streams of fiery lava, varying from five to fifty feet in depth. Fortunately all the inmates escaped safely to Waiohinu, but how narrow the escape was, and how rapid the stream flowed, may be inferred from the fact that the path by which they escaped was covered with lava *ten minutes* after they passed over it.

"On ascending the ridge we found the eruption in full blast. Four enormous fountains, apparently distinct from each other, and yet forming a line a mile long, north and south, were continually spouting up from the opening. These jets were blood-red and yet as fluid as water, ever varying in size, bulk and height. Sometimes two would join together, and again the whole four would be united, making one continuous fountain a mile in length.

"From the lower end of the crater a stream of very liquid, boiling lava flowed out and down the plateau, a distance of two or three miles, then following the track of the Government road, ran down the precipice at an angle of about thirty degrees, then along the foot of the pali or precipice five miles to the sea, the stream being about eight or ten miles in length, and in some places half a mile wide.

"This was the magnificent scene, to see which we had hurriedly left Honolulu, and had fortunately arrived at the right moment to witness, as it opened before us in all its majestic grandeur and unrivalled beauty. At the left were those four great fountains, boiling up with most terrific fury, throwing crimson lava and enormous stones, weigh-

ing an hundred tons, to a height varying constantly from 500 to 600 feet. At times these red-hot rocks completely filled the air, causing a great noise and roar, and flying in every direction, but generally towards the south. Sometimes the fountains would all subside for a few minutes, and then commence increasing till the stones and liquid lava reached a thousand feet in height. The grandeur of this picture, ever varying like a moving panorama, painted in the richest crimson hues—no person can realize unless he has witnessed it.

"From this great fountain to the sea flowed a rapid stream of red lava, rolling, rushing and tumbling like a swollen river, and bearing along in its current large rocks that almost made the lava foam, as it dashed down the precipice and through the valley into the sea, surging and roaring throughout its length like a cataract, with a power and fury perfectly indescribable. It was nothing else than a *river of fire*, from two hundred to eight hundred feet wide, and twenty feet deep, with a speed varying from *ten to twenty-five miles an hour*. As a huge boulder floated down, we imagined what if it were the iron-clad Stonewall, which had just left our harbor—would she have floated on to the sea unscathed, or melted into molten lava, and vanished from sight?

"Night soon came, and with it the scene became a thousand-fold more beautiful, the crimson of the fountains and the river doubly rich and brilliant, the lurid glare of the dense clouds and steam that overhung us and the roaring of the crater and cataract were fearfully grand and awe-inspiring. It was like the conflagration of all London or Paris, as the whole scene extended over a distance of ten miles. Add to this the flashes of lightning and the sharp, quick claps of thunder, and the reader can imagine that a scene was before us that well repaid us for our opportune visit. We never expect to see another so grand as this.

"Dr. William Hillebrand and others have visited the crater since it ceased flowing, and find that it consists simply of *a rent or fissure* in the earth, from ten to twenty feet wide. He traced it about three miles up the mountain, but it is quite probable that it extends several miles farther on, as the mountain continues smoking in a line ten miles above. There is therefore no large crater, properly speaking, but the lava flow was confined to this rupture, which continued to open lower down, as the molten lava acted on it.

"The view which we obtained of the eruption from the Kona side on the 10th, of April, was therefore a side view, and probably the finest and nearest that could possibly have been had. One peculiarity of this spouting was that the lava was ejected with a *rotary motion*, and as it ascended in the air, both the lava and stones rotated always in one direction *towards the south*. In this respect it differed from that of 1859, which we were also among the first to witness. This rotary motion of the lava would appear to have originated below the surface,

as it rolled along like waves, and corresponds with the surging sounds heard by the inhabitants of Kau during the heavy earthquake shocks.

"Regarding the rapidity of the stream of lava, since reading accounts of former eruptions, in which it is claimed that the lava flowed *forty miles an hour*, we must say that it is hardly possible to conceive of a stream flowing with greater rapidity than the cataract and river we witnessed April 10th. It reminded us of the Connecticut River in a spring flood, with the stream filled with ice and rushing over the rapids at an impetuous rate. The speed is more likely to have been twenty-five miles an hour than twelve. Where it ran down the precipice, at an angle of about thirty degrees, it was more narrow and rapid than lower down, where it spread out broader. This was the only stream which reached the sea, and flowed into it a little west of the south point of the Island, at a place called Kailikii. It lasted only five days, the eruption ceasing entirely on the night of the 11th or morning of the 12th.

"During its continuance, the atmosphere was filled with smoke so dense that the sun appeared like a ball of fire, and the whole island was shrouded in darkness. The smoke came from the rent or crater, and was highly charged with sulphur. As it spread over the island, it carried a deadly blast to vegetation, and the leaves of the more tender plants and vegetables were withered and died. It did not kill the plants in any sections, that we could learn. Opposite the point of coast where the lava reached the sea, a small conical island was thrown up in the sea, about a mile distant from the shore, consisting of mud and sand, and emitting steam from its summit. This island has become joined to the main land by the lava flowing from the new eruption. As the lava entered the sea, clouds of steam and smoke rose up, and flames of blueish fire were emitted, rising from the water to a height of from ten to twenty feet.

"During the night we were at the volcano, the air was highly charged with sulphur gas and electricity, and frequent flashes of lightning were seen directly over the lava stream, accompanied with short claps of thunder. These flashes were also observed less frequently further up the mountain.

"Two kinds of lava were erupted during the flow. It commenced with a stream of smooth, glossy lava, known here as *pahoehoe*, which was followed by the thick, dirty kind called *a-a*. Kahuku farm was nearly covered with the latter, which branched out into four wide streams, covering a space of four miles wide and long. This was followed again by the liquid or *pahoehoe*, which ran into the sea, and continued till the eruption ceased. About 4,000 acres of good pasture land were destroyed, besides which the lava ran over an immense district of worthless land.

"On the night of the 6th, prior to the eruption, there was a shower of ashes and pumice-stone, which came from this crater, and covered

the country to the distance of ten or fifteen miles each way. Generally the ashes were not more than one or two inches in depth, but in some places were found to be fifteen. The pumice-stone was very light, and appears to have been carried by the wind a great distance. Pieces two and three inches in size floated ashore at Kealakekua Bay, forty-five miles distant.

"The roaring of the crater was a novel feature to those who had never visited an eruption before. It was caused by the rocks thrown out from the crater, and the grinding or crushing process of the *a-a* as it moved along. This *a-a* flow appears composed of half-melted lava, and as it is pushed along piled up sometimes fifty or even a hundred feet high—presenting the appearance of a railroad embankment, the sides having an angle of about forty degrees, down which the lava stones keep rolling. This stream generally moves along slowly, but when the quantity of liquid lava, which floats and carries along the *a-a*, is abundant, it moves from one to four miles an hour. What makes the difference between the dry *a-a* lava and the liquid *pahoehoe*, which flows like water, is an interesting subject of inquiry that has never been settled. They both flow from the same craters, one giving place to the other in turns. Our own opinion is, that the smooth liquid variety obtains its character by long fusion, while the *a-a* variety (which appears like half-melted stones and dirt mixed together), consists of the interior surface of the earth torn off and thrown out during the eruption. An examination of the various *a-a* streams tends to confirm this theory.

"The lava thrown out during this eruption has been of a more porous nature than in most of the late ones. Some of the specimens we have seen are exceedingly light. The shower of brownish pumice-stone which preceded the lava flow was also something unusual in Hawaiian eruptions, and showed the eruption to possess a new character, perhaps the existence of more than usual steam and gases in its composition. Some have wondered why the flow ceased so suddenly —continuing only five days. The cause is probably this: so soon as the steam, which has been the active agent in producing the earthquake shocks, and in raising the lava so near to the top of the summit crater that it lightened up the clouds above it, found vents, the eruption lost much of its power, and allowed the lava to rapidly subside, and the pressure by which it was thrown out gave way.

"The quantity of lava erupted has not been probably one-tenth what was discharged in 1859, but the quantity of steam, gas and smoke discharged during one week must have exceeded what escaped during ten weeks in 1859, when the volume of smoke was comparatively small. We judge so from its density over all the group, and for a thousand miles off. This has not occurred in any late previous eruption to the same extent. The inference, therefore, may be drawn that when an unusual quantity of gases and smoke escape, a less amount

of lava will be discharged; and *vice versa*, when the quantity of smoke is small the amount of lava is increased.

"Respecting the weather during March, it may be added that it was of the same stormy character as has prevailed all over the western hemisphere, including the north and south Pacific. The quantity of rain that has fallen on the mountains of Hawaii has also been large, but to what extent these have effected the internal fires, and produced the earthquakes and eruptions, must remain only a matter of conjecture. The thermometer during the same month showed no unusual fluctuation, ranging from 68° and 70° at sunrise, and 83° to 84° at noon, with considerable regularity."

"Dr. Hillebrand communicates to the *Gazette* an account of his visit to the crater, from which we take the following:

"As the principal interest was the discovery of the main source of the stream, we at once went to that part of it where, according to common report, the lava had issued. A very light dark brown glistening pumice-stone lay scattered about long before the lava was seen. Near the flow it increased so much that the animals' feet sank deep into it at every step. We soon reached the ridge of a hill from which we surveyed the place where, according to our guide's account, the fountain of lava had been seen. This upper portion of the lava stream fills a broad valley or depression, between two parallel low hills of not more than 300 feet high, both running almost due north and south. From the western one of these hills Mr. Whitney had witnessed the eruption. From the eastern hill we in vain looked for a crater or cone. We did not make out any indication of the character of the eruption until we had crossed nearly three-fourths of the stream, which here is not far from a mile wide. Then our attention was attracted by an accumulation of scoria. Nearing this we were struck by a current of hot air, and, a little further on, found ourselves on the brink of a deep gap in the lava about 20 feet wide, but narrowing and continuing itself northward. We walked round the southern end of the gap and followed it up on the west or lee side. Before long we came to another enlargement of the fissure like the former, emitting hot air charged with acid gases which drove us back. Still continuing our march on the west side of the fissure as close as the hot gases would allow, we came in sight of a pretty miniature cone, built up most regularly of loose scoria to the height of 12 feet, and located right over the fissure. It encloses a chimney crater of about 12 feet in diameter, with perpendicular sides, the depth of which could not be ascertained. Hot gases issued in abundance. On account of the exhalation of the latter we were obliged to cross the chasm on the bridge formed by the cone to the windward side, along which we followed up steadily.

"The direction of this fissure was south 6° west, and north 6° east. The Doctor traced it up the mountain about three miles, when he was

obliged to desist owing to the covered fires, smoke and heat. In one place he came up to a cataract of lava coming down the precipitous side of the hill, a height of at least 300 feet.

"KILAUEA CRATER.

"During the great commotion on Hawaii, the ancient crater of Kilauea has undergone changes, a record of which will interest all who have ever visited it. The 'great earthquake' occurred at 4 P. M. on the 2d of April, which was followed by another of nearly equal force at 12:30 on the morning of the 4th, when the fires began to die out, and the lava in all the lakes in it to subside, till on Tuesday following there was no sign of fire or smoke, showing intimate connection with the Kahuku eruption.

"Prior to the 4th it had been unusually active, and the entire western half of the crater is represented as having been in commotion—some accounts state that it was a mass of molten lava, which has not been the case since May, 1840. On the 4th the lava began to be withdrawn, and the portion which had been in recent action subsided, so that it is now three or four hundred feet lower than it was a month before. From the Volcano House one would not readily observe the extent of this subsidence, but on going down into the part that has sunken, the extent of the change is noticed. The old south lake is now a hollow pit five hundred feet deep, with a single large cone at the bottom, surrounded with black lava rocks, but showing no fire or smoke. The result of the earthquake was to completely extinguish the fires in the crater, at least for a few days.

"From the interesting account published in the *Gazette* by Dr. Wm. Hillebrand, we extract the following relating to the crater of Kilauea:

"Allow me to relate what I learnt from Kaina, who had resided near the volcano without interruption for the last five months, and whose strong nerves sustained him during the fearful catastrophe introduced by the earthquake of April 2d. He and the Chinaman who keeps the house were the only persons who remained at Kilauea. He says that for two months preceding the first shock, viz., from January 20th to March 29th, the crater had been unusually active, eight lakes being in constant ebullition, and frequently overflowing. During all this time (the date of its appearance could not be ascertained exactly) there was in the northwest corner a 'blow-hole,' from which, at regular intervals of a minute or less, with a roaring noise, large masses of vapor were thrown off, as from a steam engine. This ceased about the 17th of March. At the same time the activity of the lakes became greatly increased, and Kaina anticipated mischief. Two days later Mr. Fornander found the bottom of the crater overflowed with fresh lava and incandescent.

"Thursday, April 2d, at a few minutes past four, P. M., the big earthquake occurred, which caused the ground around Kilauea to rock like a ship at sea. At that moment, there commenced fearful detonations

in the crater, large quantities of lava were thrown up to a great height, portions of the wall tumbled in. This extraordinary commotion, accompanied with unearthly noise and ceaseless swaying of the ground, continued from that day till Sunday night, April 5th, but *from the first, the fire began to recede.* On Thursday night, it was already confined to the regular lakes; on Saturday night, it only remained in the great south lake, and on Sunday night, there was none at all; Pele had left Kilauea. The noises now became weaker, and were separated by longer intervals. By Tuesday, quiet reigned in Kilauea. On that afternoon the lava burst out at a distance of forty miles southwest, in Kahuku.

"The great south lake is transformed into a vast pit, more than five hundred feet deep, the solid eastern wall projecting far over the hollow below, while the remaining sides are falling off with a sharp inclination, and consist of a confused mass of sharp *aa.* More than two-thirds of the old floor of Kilauea has caved in, and sunk from one hundred to three hundred feet below the level of the remaining floor. The depression embraces the whole western half, and infringes in a semicircular line on a considerable portion of the other half. It is greatest in the northern, and rather gradual and gentle in its southern portion. Entering upon the depressed floor from the southern lake, it was some time before we became fully aware of its existence. It was only on our return from the northwest corner, where it is deepest, that there presented itself through the mist in which we were enveloped, a high wall of three hundred feet of grotesque and fantastic outlines. At first we were quite bewildered, fancying that we beheld the great outer wall of the crater. On nearer approach we soon satisfied ourselves that this singular wall represented the line of demarkation of a great depression in the floor of the crater—a fact that surprised us the more, as a birdseye view from above had altogether failed to apprise us of its existence."

"The latest advices from Kilauea report that the fires are returning to the large crater, and it is not improbable that it will soon resume its old state of varying activity."

"INCIDENTS OF THE ERUPTION.

"Rev. S. E. Bishop, Principal of the Lahainaluna Seminary, says, from an observation taken by him at Lahainaluna, that the column of smoke which rose from Mauna Loa, on Wednesday morning, following the eruption, reached an altitude of seven and four-fifths miles before fanning out."

The fissure by which the Kilauea lavas mainly escaped was along the general direction of a well marked line of fault, running on an average south 60° west, and which intersects the north and south fissure on Mauna Loa at Kahuku, near to where the great lava fountains spouted from it. Some observers, and among them the late Mr. Coan, thought that the Kilauea lavas—which began subsiding on the

2d of April, the day of the great earthquake, and had disappeared entirely from the crater on the fifth of the same month, two days before the Kahuku outburst—joined in the eruption from the Mauna Loa fissure. Mr. Coan examined carefully the whole course of the southwesterly fissures extending from Kilauea, finding also a spot—which nobody else had hitherto done—where much lava had risen to the surface, and says: "This series of small eruptions is about eleven miles southwest of Kilauea, and it shows distinctly the subterranean path taken by the igneous flood which left that seething cauldron on the night after the rending earthquake of April 2d. That shock doubtless opened a pathway for the struggling fires, and they went off in a south-western course, under the highlands of Kau, (fault precipices? W. L. G.) uniting with the subterranean fires of Mauna Loa, and finding a fuller vent at Kahuku, on the seventh of April." (Quoted in Brigham's Hawaiian Volcanoes, p. 581.)

It has been objected to this view, that the Kilauea lavas, although perhaps one thousand feet or more above the level of the Kahuku outflow, could hardly have been able to make their way out against what was probably a higher head of lava in the north and south Mauna Loa fissure, higher up the mountain, and from the continuation of which the fountains clearly arose. But we have to remember that the liquid pressure in these long underground fissures, would depend more perhaps, on the size and directness of them, and upon the supply of hot lava, than upon the elevation of the source; in other words, upon the relative viscidity or liquidity of the lavas in each fissure. A small stream of lava falling down even a perpendicular precipice solidifies as it falls, like melted tallow on the side of a candle, but a powerful and therefore hot and liquid stream of the same lava will rush at the rate of from twenty to forty miles an hour down a moderate slope. Whether part of the Kilauea lavas escaped on the Mauna Loa fissure or not, may well remain an open question, an interesting one indeed, in many respects, but hardly involving any essential principle.

And here we would remark that, notwithstanding this simultaneous discharge of lavas from the two mountains, we do not regard the fact as having much or any bearing on the question of a deep-seated connection between their conduits. The same earthquakes opened out the cracks—already there—from both reservoirs, and they both discharged their contents through the rents. This may well have happened, whether there is a permanent liquid connection between them or not. It is rather the steady rise together, and the marked quietude of one mountain after the other has discharged its lavas—as their whole history indicates—that leads to the inference of a deep-seated liquid, or shall we say semi-liquid, connection. This viscidity of the lava working its way up through narrow and tortuous underground passages, which always tend to close below from the pressure of the rocks above, when not occupied by lava under a head of pressure nearly

equal to that exerted by the weight of the superincumbent rocks, may help to account for the slowness with which the lavas return to Kilauea after a discharge has taken place, notwithstanding that they are, by our hypothesis, connected through the sub-crust stratum with a *now heavier* column twenty miles from them in another mountain. It is perhaps hardly necessary to refer here to the great loss which must occur in such a semi-liquid and perhaps compressible substance as lava, in the transmission of pressure from and through one column to and through another, when it has to act—by our hypothesis—through a large portion at least, of the probably immense mass of the molten substratum. It becomes indeed a question of time, and it is an operation rather analogous to that of the gradual movement of solids under great pressures, and which, when great masses and depths are concerned, tend also to "flow" and to approach one level, but in their case a very long time is required to produce any effect.

However, after the great discharge and disappearance of lava from Kilauea in 1868, and the subsidence of a large portion of the bottom of the crater some three hundred feet, the fires soon began to appear again. We have already (see Chap. VI., page 160) referred to the gradual filling up of Kilauea crater after 1868. We will merely say here that it took eighteen years, or till 1886, to fill up so as to open the fissures below and escape, when another, but much smaller, subsidence occurred. But let us see what Mauna Loa has been about in the meantime.

It was rather more than four years after the great discharge of 1868, from the two volcanoes, before another eruption occurred. We extract the following account from a letter written by Rev. T. Coan, dated August 27th, 1872, to J. D. Dana, and which was published in the *American Journal of Science* for November, 1872, Vol. IV. He says:

"On the night of the tenth inst., a grand and lofty pillar of light rose from the summit of the mountain to the height of some two thousand feet. This was directly over the great terminal crater, Mokuaweoweo. It was distinctly seen at first from Kilauea and Kau.

"On the evening of the thirteenth we had the first *perfect* view from Hilo. The illuminated cloud of steam and gases which hung over the crater, sometimes rose in a well-defined vertical column to a great height, and then the higher portion would expand, forming an inverted cone; again it seemed lighted up above the mountain and spread out like an umbrella, over the crater. The changes of form, the expansion, contraction, and convolutions of the illuminated pile, could be distincly marked, and also the rapid variations in brilliancy dependent on the greater or less intensity of the fiery lavas in the abyss below.

"It is now seventeen days since we first saw the eruption, and still the great furnace is in full blast. The action is evidently intense. Of

all the demonstrations made in this vast cauldron on the summit of the mountain since our residence in Hilo, none have equaled this in magnitude, in vehemence, and in duration. As yet it is confined to the deep crater; and we know not whether the terrific force now raging in this abyss will rend the walls of the mountain and let out a flow of lavas to the sea, or spend their fury within the recesses of the mountain. The scene from the border of the crater must now be fearfully grand."

As this is the first summit crater eruption of Mauna Loa which has been properly observed and described, and lasted with, perhaps a few intermissions, no less than eighteen months, we copy the following account of the scene as viewed from its edge. It is taken from the *Pacific Commercial Advertiser* of September 21st, 1872, and is published in the number of the *American Journal of Science* in which Mr. Coan's letter appears:

"CRATER OF MOKUAWEOWEO.

"There before us, at our feet as it were, yawned a terrific chasm, with black perpendicular walls, carrying the eye down some eight hundred feet, to where, in the inky blackness of the lower basin sprung up in glorious sparkling light, self-born, a mighty fountain of clear molten lava. * *

"Looking straight across and below us at a distance of three-quarters of a mile, in an air line, there arose from a cone located near the southwest corner of the lower basin a magnificent fountain of liquid lava, about seventy-five feet in diameter, that sent its volume of brilliant, sparkling molten matter to a height estimated at five hundred feet in a compact and powerful jet. * *

"We watched steadily the grand fountain playing before us, and called frequently to each other to note when some tall jet, rising far above the head of the main stream, would carry with it immense masses of white-hot glowing rocks which, as they fell and struck upon the black surface of the cooling lava, burst like meteors in a summer sky.

"As soon as we reached the summit level of the mountain, we heard the muffled roar of the long pent up gases as they rushed out of the opening which their force had rent in the basin's solid bed. And now that we were in full view of the grand display, our ears were filled with the mighty sound, as of a heavy surf booming in upon a level shore, while ever and anon a mingled crash and break of sound would call to mind the heavy rush of ponderous waves against the rocky cliffs that girt Hawaii.

"At night the jet looked loftier, and gazing intently into the fiery column with a good glass that we had, we could see the limpid, sparkling, upward jet rising with tremendous force, from out an incandescent lake."

As the reader should clearly comprehend the nature of these great

lava fountains—respecting which some doubts have been entertained —and as we saw the continuation of this same fountain on June 6th, 1873, (see ante pages 166–7,) we would repeat here, that as we saw it, it was nothing more or less than "a mighty fountain of clear molten lava," as the above writer describes it. We were also within three-quarters of a mile of it. It was splendidly lighted up by its own white-hot incandescence, and we observed it carefully, for hours through a good binocular. There was not a symptom of its apparent size being increased by "incandescent gases." It was simply molten lava, carrying up, however, some solid matter, and topped probably by molten lava-froth. We go a little further, and would observe that during our visit, we heard no "muffled roar of the long pent up gases," neither did we *see* anything to lead us to infer that there were any gases escaping. It is probable that these had all escaped before we arrived. We heard the "muffled roar," it is true, which we attributed to the falling of the lava of the fountain into the lake of molten stone from which it rose. The noise, in fine, of a cataract like Niagara—but of molten glass instead of water—or as the above writer himself so well describes the noise, "of a heavy surf booming in upon a level shore," intermingled with the sound of the "heavy rush of ponderous waves against the rocky cliffs that girt Hawaii," when the falling lavas and solid masses were thrown, as they sometimes were, outside of the incandescent lake on to the solid rocks.

Let us observe, however, in order to prevent any misunderstanding of our views, that we regard the evidences of great and violent escapes of vapor, gases and smoke, from orifices of eruption on Hawaii, at the first outburst of lavas especially, to be clear and convincing. We refer to them in numerous places in this volume. What we contend for is, that these gases and vapors are accessories and not necessary to the main action, either in these fountains or elsewhere. The operations seem to go on without the help of elastic gases, and after they have all escaped, with the exception of confined and heated air, which must always be present where molten lavas are in violent motion, either from hydrostatic pressure, convection currents, or in running down a slope. It was the first of these causes, as we have interpreted the facts, that alone produced the fountain which we saw in 1873, although the next two causes no doubt, acted in producing glass lava-foam and glass filaments. In these eruptions there are three kinds of exhibitions of vapors and gases, and which should be kept distinct in our minds; first, that of the uprush of vapors from newly opened orifices; secondly, that of the steady rising, vertical column, or the long trail of smoke, which keeps as distinct for a long distance as the smoke from a steamer or a factory chimney; and thirdly, "the hanging clouds," which—as we believe—are caused simply by the expansion and rise of the moisture-laden air heated over a lava fountain, or a lava lake, or a fresh lava flow, and condensed in a cooler upper stratum,

and which hanging cloud, may or may not, be mixed with glass filaments, smoke and gases. There is also, of course, usually some smoke and vapors rising from fresh lava streams, where vegetation has been burnt and is smouldering, or when the lavas flow in the beds of streams, or into the sea, or over underground waters, or over damp places. Steam will generally also be seen over recent lava flows, long after all seems cold on the *surface*, whenever it rains and after rainy weather. All these vaporous exhibitions, however, are a result—not necessarily connected with the cause—of the grand volcanic phenomena of Hawaii.

But we must now go to Mr. Coan's letter, already quoted, to learn what he says about Kilauea in connection with this wonderful fountain of molten lava of 1872-4, confined entirely within the summit crater of Mauna Loa. He says, writing in August, 1872:

"Ten thousand feet below the summit fires is Kilauea"—(and we may add twenty miles distant). "This crater has also been very active of late. The south lake, which was so deep when I last wrote you, has long been filled, and it has overflowed many times, sending off broad streams of incandescent lava, filling up the great basin of 1868, elevating the southern portion of Kilauea, raising cones that puff and screech, and throw out vapor, hot gases and sulphur. The present activity looks like some kind of sympathy with the summit furnace."

We should say that we mainly confine ourselves to the late Mr. Coan's published letters with regard to the state of Kilauea, as the reports from some quarters often refer to it as very active when there may be nothing to warrant such a description. The Rev. T. Coan, from years of experience, knew exactly what he was writing about; and although his language may be sometimes rather florid, his reports are thoroughly clear and reliable. We have never been able, in our examination of what he has written on Hawaiian eruptions, to detect a mistake as to matters of fact which came under his own notice, whilst his hypotheses explaining what he saw seemed to be always sagacious, and, as we think, generally correct. He addressed another letter to Mr. J. D. Dana dated January 6th, 1874 (published in the *American Journal of Science*, May, 1874. Vol. VII.), from which the following is a copy of the extract:

"You are aware that the great summit crater of Mauna Loa, Mokuaweoweo, has, for a number of years, shown but few and feeble symptoms of activity, until the past year. For a few days in August, 1872, there was a brilliant light in the crater; and again on the 6th and 7th of January, 1873, there were vivid demonstrations, which roused the attention of many witnesses. But it was not until the 20th of April, 1873, that a continual exhibition of mountain pyrotechnics commenced. From that day to the present, now almost nine months, the action within the great cauldron has not remitted. Most of the time

the boiling has been vehement, and the scene was never more brilliant than a few nights ago. Sustained jets of molten rock were constantly rising 50 to 200 feet within the mural cauldron, and the surgings, puffings and roarings, have been heard low down the sides of the mountains, and, as some testify, as far as Reed's Ranch, probably fifteen miles.

"But the great marvel of this eruption is its *duration*. We have seen nothing like it before in this crater. The eruption of 1855–6, flowed fifteen months; but this rent the mountain laterally, and flowed longitudinally; whereas the present eruption has, as far as we know, made no lateral vent and found no outlet. The action is vertical, and is simply a gigantic mountain-pot of boiling lavas.

"Can you tell what sustains these Plutonic fires, and lifts those burning columns and agitates that fiery abyss at the height of nearly 14,000 feet? What are the forces which move or shake with so terrific power the foundations beneath us?

"Kilauèa, during all this time, has been unequally active. Sometimes the action has been intense, and the illuminations brilliant; and again Madame Pele has been quiet.

"But the great depression in Kilauea, caused by the eruption of 1868, is fast filling up by repeated overflows from the south lake, while, all around that lake, a vast mound is rising whose summit is nearly as high as the southern rim of Kilauea, and it may soon overlook it."

A correspondent of the *Hawaiian Gazette* of September 3, 1873, writes to that paper as follows:

"THE VOLCANO OF MAUNA LOA.

"This lofty volcano is burning as brilliantly now as on the night when it burst forth—January 7. On Wednesday night, August 27th, it lit up the entire island, and its glare could be seen by vessels passing more than a hundred miles distant. Early in August Dr. O. B. Adams, Surgeon of the Costa Rica, accompanied by his wife, visited the crater, and found it in magnificent action. The weather was intensely cold, water in their containers freezing solid during the night. It was impossible to induce the native guides to remain at the summit longer than one night, and the Doctor was, in consequence, compelled to make a shorter stay there than he had planned. Mrs. Adams is the third lady who has made the ascent during the past year, and we doubt not feels amply repaid for the excursion. The column of molten lava, which is thrown out of the summit crater, varies from 200 to 500 feet in height, and assumes all the various forms of a grand fountain of water. It is singular that the eruption should continue with so little change for over seven months as it has at such a great elevation —nearly 14,000 feet above the sea.

"While this display is going on at the summit, the old crater of Kilauea (4,000 feet above the level of the sea) is also unusually active. Governor Lyman informs us that early last week the old south lake

overflowed its rim, and that a stream of molten lava has been running own towards the depressed center of the crater, the stream flowing at a very rapid rate, and the lava disappearing beneath the crust. The south lake is divided into two smaller ones than formerly, separated by a wall, and yet so distinct are the sources of supply that the lava in one will rise fifteen feet, and subside again apparently without affecting the other, although located so near each other as to leave the conviction in the mind of a casual spectator that they are connected. In addition to this phenomenon, there is another equally singular. A miniature cone, seventy-five or a hundred feet high, located near the south lake, at times sent a stream of lava out of its summit aperture, which flowed down its sides into the lake. This occurred without affecting the lava of the lake in any perceptible degree. The volcano, during the last twenty years, has never presented more varied and attractive phenomena than it does now, and travelers who can spare a month to visit it will be well re-paid. Four weeks give ample time to witness the principal points of interest on Hawaii and Maui."

Under date of October 6th, 1874, Mr. Coan again addressed Mr. J. D. Dana, the following extract from which letter is published in the *American Journal of Science* for December, 1874, Vol. VIII., page 67:

"Kilauea has been very active for the greater part of the past year. The great south lake has been full and overflowing much of the time; and the great central depression of 1868, in the crater, has been filled up by deposits about 200 feet, while the region around the great south lake (Halemaumau) is a truncated mountain nearly as high as the outer upper edge of the crater.

"Mokuaweoweo, the summit crater of Mauna Loa, has been in action for eighteen months. For the most of the time the action has been violent. Of late it has decreased, and there is the appearance that it will soon cease.

"We have had few earthquakes at Hilo during the year, and these have been feeble. They are often felt near Kilauea, in the district of Kau."

In January, 1875, Mokuaweoweo again displayed the now usual lava fountain without any lateral discharge. The following note from Mr. Coan is published in the *Hawaiian Gazette* of January 20, 1875, with some remarks by the editor:

"HILO, Monday, January 11.

"I open this letter to say that brilliant action commenced in the summit crater of Mokuaweoweo before daylight yesterday morning, the 10th. I think we have never seen the light more vivid, or the action grander in that crater. The heavens are aglow at night, and a grand pillar of cumulus clouds coronate the mountain by day. If any one wishes to visit banks of snow and molten lakes of fire at one time now is his opportunity. T. C."

"The summit chimney or crater of Mokuaweoweo had been closed for about eight weeks, during the latter part of which time the earthquake shocks had been increasing in strength and frequency. This new opening of the volcano will serve as a safety valve, and so long as it lasts there will not probably be any more severe shocks nor any other eruption on Hawaii, which some have thought might soon occur."

In the same newspaper of February 10, 1875, the following appears:

"THE VOLCANO.

"H. B. M. ship Reindeer returned on Thursday last from Hilo. During the ship's stay at that port her officers visited Kilauea. Captain Ansen informs us that the old south lake appears very much as described by us in December. The two lakes were quite active, and while the party were on the bank of lake Kilauea they had the remarkable good fortune to witness the formation of a third lake between it and Halemaumau. These three were left in action, and are described us surpassingly grand. At the Volcano Hotel Prof. Forbes and his party were found, having made the tour from Kailua to the summit crater of Mokuaweoweo and thence down to Kilauea—a midwinter feat of which he may well be proud. The summit of the mountain and also part of the floor of the interior of the crater were found to be well covered with snow. The jet was found by him to be 265 feet high. Of the two craters he thinks that of Kilauea much the finest, and calculated to afford the visitor the most satisfaction."

And in the *Pacific Commercial Advertiser* of about the same date appears the following communication:

"HILO, January 3d, 1875.

"There was a great deal of activity in the crater of Kilauea from Dec. 26th to the 29th. On the evening of the 26th, the lava commenced to flow on the side of the hill of the south lake, and in the morning it had covered two superficial miles, when it ceased. Those at the Volcano House say it was a grand sight during the night, and in the morning some beautiful specimens were obtained from the flow. Mr. Reed arrived at the Volcano House from his ranch in the evening of the 29th, and observed a great deal of activity in the crater, but being so accustomed to Kilauea he took no particular notice, until about midnight he was awakened from sleep by a terrific roar, accompanied by occasional explosions more deafening than all the artillery of a grand army fired at once. The whole heavens were lit up by the glare of the volcano. Upon looking at the the crater, the south lake was seen to be overflowing its banks on all sides.

"Mr. Reed passes Kilauea four or five times a month, and has for the past fourteen years, but never saw it in such a state of activity. He left for Hilo after six o'clock in the morning, but knew nothing of the earthquake until he arrived here. Old residents say that with two exceptions—in 1855 and in 1868, and on the last occasion the whole

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island was shaken fearfully—there has been nothing like the recent one. A continuous shake of two or three minutes, like the earthquake of Dec. 29th, must have torn everything to pieces."

This outburst in Mokuaweoweo lasted, as nearly as we can discover, about one month; thus making two years and a half of a nearly continuous lava fountain, entirely confined within the summit crater, and with no outflow whatever on the flanks of either Mauna Loa or Kilauea. In the latter, the lavas had been continually rising since 1868, and during most of the latter part of the period have been described —as we have seen—as extremely active. But the sides of both mountains held firm. The long eruption in Mokuaweoweo seemed to have clogged, or sealed up the bottom of the crater, although the lavas may have been forced some distance into side fissures, without breaking out on the flanks of the mountain. But this state of affairs could not continue indefinitely whilst the lavas were constantly rising.

At length, on the 14th of February, 1877, *again nine years* after an outflow, (the great discharge of 1868, from the sides of both volcanoes) the very summit of Mauna Loa, not the crater bottom hundreds of feet below, but a great rent on the flat top of the mountain, sent forth a burst of smoke, vapors and white-hot molten lava, that not only lighted up the whole Island of Hawaii, but the people in Waikapu, Island of Maui, over a hundred miles away, "supposed that the cane fields and mill buildings of Makee's plantation," (on their own island, but in the line of sight to Mauna Loa,) "were on fire. One spectator who has witnessed a number of eruptions states that he never saw a more magnificently illumined smoke-cloud from any previous one."

"Mr. C. J. Lyons" (land surveyor), "writes us" (*Hawaiian Gazette*, 21st February, 1877,) "from Waimea," (situated on a high plateau some thirty miles north, and in full view of the top of Mauna Loa) "that the smoke masses were ejected to a height of not less than sixteen thousand feet above the top of the mountain, where they hung, forming a dense stratum of smoke. The velocity with which they ascended was such that the first 5,000 feet were passed inside of a minute."

This outburst of vapors and molten lava on the great flat summit of the dome of Mauna Loa, lasted ten days, or until the 24th February. *On that day* a submarine eruption took place in the sea at Kealakekua, some twenty miles from the summit crater, and on the west side of it. It was accompanied by an earthquake. A crack was afterwards found running three miles inland, in the same straight line as the summit crater fissure and that of the submarine eruption, which extended a full mile out into the sea. Water was seen and heard pouring into this crack and steam rising from it.

This eruption was first observed in the sea, at 3 o'clock in the morning of the 24th February (while dark), "about a mile from shore, and it appeared like innumerable *red, blue and green lights*. Some

thought these were the steamer's lights—only they were so numerous as to excite some consternation."

"The water in that locality is very bold, the bottom being formed by successive ledges of old lava deposit, running from twenty fathoms near the shore, the lead suddenly dropping to forty and then to sixty and a hundred fathoms, until at a mile or so no bottom is to be found."

The coast line here we consider to be on a north and south fault or fissure, which view these soundings confirm. Here also are evidences (in a precipice) of the fault and fissure running near the line of crack towards the top of the mountain. This lower eruption broke out, as is usual, at the intersection of the two fissures. There is an evident reason for this as we have elsewhere explained.

When the inter-island steamer drew near the spot on the morning of the 24th, "the captain, on the bridge, descried what he had first thought was a school of blackfish or small whales, but which he soon pronounced to be a submarine eruption, lumps and blocks of lava—of course of the lightest known variety, or it would not have floated—being seen in considerable quantities." We would just remark here that we received many specimens of this, picked out of the sea by people in boats, and it is now by no means the lightest variety of lava, and would sink readily; but Mr. H. M. Whitney clearly explains this in another communication in the *Hawaiian Gazette* of February the 28th, he having been in one of the boats picking up the lava. He says: "Blocks of lava two feet square came up from below, frequently striking and jarring the boats. In one minute we counted no less than six of these stones hitting the boat; yet, as the lava was quite soft, no harm was done. Nearly all the pieces, on reaching the surface, were *red hot*, emitting steam and gas strongly sulphurous. At one time the surface of the sea was covered with several hundred pieces of this lava; but we observed *as soon as they became cold they sank* as rapidly as they had risen. Several were taken into the boats perfectly *incandescent, and so molten in the interior* that the lava could be stirred with a stick like pudding, the water having *penetrated not more than an inch from the surface.*"

There is much material for reflection and for instruction in the behavior of these lavas rising in the sea. To show that they were not all soft, another account says: "Several pieces came in contact with the bottom of the steamer, one at least with sufficient force to knock off a piece of copper on the bow a foot long." They exhibit in a marked manner the difference in specific gravity between hot and cold lavas, the former inflated by gases which *condense* when cold, but need not necessarily escape. Much of the gas, however, evidently did escape from the molten rising lava, while much of it was not steam, as it appeared at the surface of the sea as red, blue and green flames. These facts indicate also, what is probable, that moderate quantities of

water intimately mixed with white-hot molten lavas at considerable depths, and under pressure would, on rising to the surface, not appear as steam, but the water would become disassociated. Much of the oxygen might combine with the iron which exists in superfused basic lavas, whilst the hydrogen on escaping from the lava at the surface would be ignited and show as flame. Such an operation merely presents the results of the common experiment of passing steam through iron filings in a red-hot gun barrel, and manufacturing hydrogen gas.

This eruption probably disposed of much more lava than that which could be actually seen, both underground, in the fissure between the central column and the sea, and over the sea bottom. It is known from observation here, that red-hot *pahoehoe* lava will keep hot and flow under water without producing much commotion.

The mountain had now been relieved, and no eruption took place anywhere on either volcano until May 1st, 1880, three years and a quarter afterwards.

We ought perhaps, to refer in this place, to the fact that the lavas of Kilauea have often subsided and retired out of sight temporarily. Mr. H. M. Whitney has recorded one case of this kind in 1877, and Mr. Lentz, formerly of the Volcano House, one in 1880. There have, no doubt, been many others. In these temporary subsidences there is no sinking of the floor of the crater, although part of the cone about Halemaumau may disappear. No eruptions at the surface were recorded in these instances, and the lava reappeared in a few days or weeks, and soon acquired its normal level. It is probable that these subsidences are produced by the same cause as those when the crater floor subsides and no lava is erupted, namely the opening and filling of underground fissures. Mr. Whitney attributes the temporary subsidence in 1877, to an earthquake. It may seem remarkable that on the hypothesis of the liquid connection of these lava columns with the general molten substratum on which the earth's crust rests, the lava should not rise more rapidly than it does. It has to be remembered however, that five hundred feet, the probable limit of subsidence in these cases, is not half of one per cent of the liquid column assumed to be twenty miles deep. The liquid is viscous, and the small openings by which it has to return become clogged with debris through which the rising lava has to melt its way. The process of melting solid rocks is further a cooling process for the molten lava, so that the effect is to seal up the openings until the lava finally melts or breaks its way through.

After the temporary subsidence in 1877, Kilauea was pursuing its usual course, the lavas rising and running over. The *Hawaiian Gazette* of September 12th, 1877, contains the following:

"Travelers who were visiting the crater of Kilauea lately represent it as very active and brilliant. The old south lake is now about 1,000 feet in length and 600 feet in width, boiling and spouting as of old."

On May 1st, 1880, a light was seen over the summit crater of Mokuaweoweo, when the mountain—and indeed the whole island—was so brilliantly illuminated that "fine newspaper print could be read on the sea shore, fifty miles distant from the crater."

Mr. Coan, writing to the editors of the *American Journal of Science* May 6th, 1880, after describing the summit outbreak, says:

"Since my former letter, dated June 20, 1879, Kilauea has resumed great activity. Rarely in its recorded history have the fires been more intense, or the filling more rapid." * * * "Lateral streams of liquid rock are bursting through the scoriaceous sides of Halemaumau—the lake and cone in the southwest part of the crater—and flowing down the declivities into the central depression, adding stratum to stratum, while the great lake boils and dashes its waves against its walls, and sends its burning spray high into the air." (No. 115, Vol. XX.)

"Here," (says Mr. H. M. Whitney, writing from Kau, May 6th, see *Hawaiian Gazette*, May 12th, 1880,) "no premonitory shake or noise was felt or heard, the eruption (in the summit crater) having commenced as quietly as a moonrise, and there has been nothing connected with it to create any alarm, or any feelings but those of wonder and delight, at this grand exhibition of nature." * * * "*Kilauea*, during the past two weeks, has been very active, with frequent streams flowing from the old south lake, and fresh lava pools forming in various parts of the crater. During former eruptions the action of Kilauea has been lessened, but in this case there seems to be no connection between the two; and both fires have probably been stimulated by the immense quantities of rain and snow which have fallen during the past few months."

The fires may possibly have been so stimulated, but now, nearly the average period has elapsed, (3.55 years by our tabular statement) since the last eruption anywhere on the two mountains. The lavas been steadily rising in both columns and are ready to break out, rain or no rain. The eruption at the summit commenced without earthquakes, and "as quietly as a moonrise." The sides of the mountain however, hold firm and retain the liquid flood. The light at the summit disappeared in a few days and all seemed to go on as usual. Why *should* the action of Kilauea *now* be "lessened?" Neither mountain has experienced any relief by an outflow of lava. But the molten reservoirs are near "flood-level," as Prof. Dana terms it, and on November 5th, of the same year, (1880) there commenced on Mauna Loa one of the greatest outflows of lava on record, just three years, seven months and twenty-one days after the outbreak of 1877.

Before describing this great eruption, however, let us quote a paragraph from the *Hawaiian Gazette* of May 19th, 1880, soon *after* the premonitory Mauna Loa outbreak of May 1st, showing the continued activity of Kilauea:

"The magnificent outbreak on the summit of Mauna Loa appears to have subsided, but Kilauea is raging with the most intense activity. At times the surrounding country trembles with the fury of the action in the crater. Immense volumes of lava are pouring out of Halemaumau and are rapidly filling up the vast bowl. At times the whole lurid mass seeths, bubbles and boils with great waves of fire rolling a frightful surf from side to side. Visitors rarely have such a display as that now visible at Kilauea."

Mr. Whitney's account of the activity of Kilauea, was *during* the eruption in the summit crater, now we find it, immediately afterwards, so violent that the country about Kilauea "trembles with the fury of the action in the crater." Both mountains are ready for an outflow somewhere. We condense the following account from correspondents of local newspapers during the nine months of the eruption:

On the 5th November, 1880, a stream of lava broke out "about six miles north of the summit crater of Mokuaweoweo on Mauna Loa." In a few days there were several orifices formed lower down, along, or near the line of fissure from which the 1852 and the 1855–6 flows proceeded. These eruptions were accompanied by the usual white-hot lava fountains, brilliant reflections and immense volumes of smoke. This fissure runs along a low ridge, or spur, formed by many successive eruptions from it in past ages. On this occasion three distinct streams poured out, one going north-eastward, quickly reaching the flat between Mauna Loa and Mauna Kea, one ran southward towards Kau, whilst the third came between these two in the direction of Hilo. These flows have been called fifteen, ten and forty-five miles long, each, respectively, and there can be little doubt that their united lengths reached seventy miles. The streams are of all widths from a few yards to a few miles, and different areas of many square miles in extent are to be found on the plateau between Mauna Loa and Mauna Kea, covered with lava from this eruption, "ten to two hundred feet thick." It would be useless to attempt an estimate of the cubic contents of these lava streams without a survey. Those who have examined them and seen them from the mountain with the 1855–6 flow, also in sight, consider them to show much more lava than the latter unprecedentedly large outflow. As far as we can judge from the different accounts, a very large proportion of the whole bulk of the 1880–81 flow was ejected within the first few weeks. Indeed, the northerly and the southerly branches had, in that time finished their course, but the central stream kept steadily pouring out above and advancing for nine months, until August, 1881, when it stopped at the outskirts of the town of Hilo.

Amongst the incidents connected with this flow, one interesting feature was a heavy cloud which hung for weeks, in one spot, over a flat to the westward of Hilo, where the lava had got dammed up in its course, and formed a large half-molten lake. We have two oil

paintings from sketches on the spot, by Mr. C. Furneaux, of this phenomenon. In one, by night, the cloud is seen blood-red, from the reflection of the white-hot lava below. In the other, by day, a water-spout is seen descending from the cloud, whilst the lower end is being driven off in steam by contact with the hot rocks. Here there was no vapor arising from the lava and there were no orifices of eruption. Much smoke however, is seen arising around the margin of the lava from the burning woods, but distinct from the hanging cloud, and which is so often seen over heated volcanic areas on Hawaii, and is apparently caused by the indraught of the moisture-laden air towards the heated area, and which air, when thus heated, rises, until it gets too high and distant to be further heated by the lavas below, and then the excess of moisture—which heated air is always capable of retaining—becomes condensed when it arrives at a cooler stratum.

Some interesting instantaneous photographs have been taken of parts of this flow, especially one set of eight, taken within a few minutes of each other, showing first a precipice in the bed of a stream, and then how the lava came pouring over from above, how it appeared as a steady cataract, how it evaporated the water in the pool below, gradually filling it up, until all became a level, or rather a slightly sloping plain, which it did in one hour and forty minutes from the time the lava began to pour over. We happened to see another instance of this kind at this flow, but it was on a smaller scale, and the lava "guttered" over the declivity, rather than flowed. The liquidity of these lavas, as one is taught everywhere on Hawaii, is only a question of their heat, and the heat which they retain depends upon the volume, or rather upon the mass in proportion to cooling surface, and whether that surface is freely exposed to radiation or not.

Captain Dutton, in his "Report on Hawaiian Volcanoes" (page 132), notices this eruption of 1880–1. He visited the highest portion of the flow, which he found to be 11,800 feet above the sea level. He describes exactly the condition of affairs which we observed on the part of the fissure above the main outflow of 1868, that is, a long crack of varying width and depth extending up and down the mountain, out of which had issued streams of vesicular, dark olive-green, basaltic obsidian, and with no trace of a crater, at least near this spot. At the crater of the 1859 flow, as we remark in another place, a *light-green* vesicular semi-transparent basaltic glass flowed over the lip of the crater in great waves, which cooled into glass-foam as they ran, in the form of breakers.

The reports that were published from time to time of the state of Kilauea during the period of this flow, seemed to indicate the usual varying phases of activity. The lavas on the whole kept rising, but we find no report of the threatening aspect which Mr. Coan and others described *before* the outflow of 1880. This average, but still varying, state of activity continued until 1886, during all which time—with,

however, some small temporary subsidences of the lavas—the bottom of the whole crater was gradually filling up, and the lava lake and surrounding cone of Halemaumau rising above all, threatening to overtop the outer rim of the great caldera.

Here, however, we should refer shortly to

THE SUBMARINE ERUPTION

off Puna in January, 1884, which was described in the *Pacific Commercial Advertiser* of January 31st, as follows:

"A correspondent residing in Kau, writes: 'We have been greatly interested in a volcanic submarine eruption which occurred on Tuesday morning, January 22d, about half a mile off Apua Point, the east cape of Hawaii, and some fifteen or twenty miles from the crater of Kilauea. A column of water, like a dome, shot several hundred feet up into the air, accompanied with clouds of smoke and steam. All Kilauea range, from the sea to the crater, was enveloped in the dense clouds that issued from the water, and the ocean was also covered with clouds of steam as far as the eye could reach, while rainbows spanned from Kilauea to the ocean. In the afternoon the wind blew a hurricane, uprooting trees all around us, but this high wind continued for only four or five hours. The next day was bright and clear, but a heavy bank of clouds still hung over the scene of the eruption and over the Kilauea ridge. No further eruption, however, has been observed at sea.'"

We could not learn that any special change took place in Kilauea about the period of the submarine eruption, fifteen or twenty miles from it. If it was caused by an outflow of lava through a fissure directly connected with Kilauea, we should have expected to hear of a marked subsidence in the crater, but if the submarine outflow was only connected with Kilauea through the sub-crust stratum, the only effect on Kilauea may have been a retardation of the rise of the lavas, which means, in fact, no special action in the crater. The slow withdrawal of the lavas which may have been produced by the remotely connected outflow in the sea, may have been about equalized by the general rise which, as we have seen, is constantly going on in both mountains.

This *retardation* seems, indeed, to be the effect of the Mauna Loa outflows on the lavas in Kilauea, for between 1823 and 1840 inclusive —seventeen years—the bottom of Kilauea crater fell in three times, giving two known periods between, of nine and eight years each. Up to 1840 only one small outflow on Mauna Loa had ever been recorded —that near the summit in 1832. But it was twenty-eight years before the next subsidence of the bottom of the crater of Kilauea occurred, (in 1868,) and during this time there were *five outflows* from Mauna Loa, at periods of three, eight, seven, three and four years. After 1868, the Kilauea lavas kept rising for eighteen years, without any subsidence of the crater bottom, until 1886, when the breakdown of

that year took place. During this eighteen years there had occurred four *outflows* from Mauna Loa, one outflow in the sea, and five eruptions confined to the summit crater, Mokuaweoweo. It appears then, that the outflows of lava on Mauna Loa relieve Kilauea. If so, we have two lines of evidence pointing to a sub-crust liquid connection between the two conduits. The lavas in both appear to rise and rage together and calm down together, whilst an eruption has never been known to occur on Mauna Loa—either in the summit crater or from the flanks of the mountain—until the lavas in Kilauea have well risen, and never less than three years after a great subsidence in Kilauea. On the other hand, during the period before 1843, when the flanks of Mauna Loa did not discharge lava at all—except once in 1832, when both mountains erupted together, and Mauna Loa only round the summit—Kilauea crater discharged its contents with a great subsidence of its solid floor, three times in seventeen years. In the subsequent forty-six years, whilst Mauna Loa discharged its contents nine times, Kilauea only discharged its lavas, with subsidence of the floor of the crater, twice; the last one—that of 1886—being quite small in comparison with those previous.

All this is in agreement with the impression generally entertained, that the activity of Kilauea has declined since 1840. It does appear so, but if the relief given to Kilauea by discharges from Mauna Loa is the reason for it, it is an accidental—not a constitutional—decline of energy. To express the apparent result in a few words—an eruption from either mountain relieves both. It may be further remarked, that the phenomena at each eruption—in all but one doubtful case, that of 1868—do not lead to the inference that the liquid connection which seems to exist, is through direct superficial fissures, but rather through a more remote channel.

We now arrive at what is often called the "break-down" in Kilauea of March 6th, 1886, and the rapid return of the lavas to nearly their old level. This phenomenon has been so well observed, sketched, photographed, surveyed and reported on, that we can present a summary of the facts and figures with much confidence as to their correctness, and we refer the reader for further details to the *American Journal of Science*, No. 185, Vol. XXXI., page 397, and No. 194, Vol. XXXIII., page 87, with maps and reports to Prof. W. D. Alexander, Surveyor-General of the Hawaiian Islands. Also on page 102, an article on "Volcanic Action" by James D. Dana, having special reference to this and to Hawaiian eruptions.

The following are copies of two letters received by the Hon. S. G. Wilder from Mr. J. H. Maby, Manager of the Volcano House:

"KILAUEA, March 8, 1886.

"Since last writing there has been considerable of a change in the crater. Saturday evening, March 6th, both the old and new lakes were unusually full and brilliant-looking from the house, and re-

mained so until 9:30 P. M. of the 6th instant, at which time there commenced a series of earthquakes, forty-three in number, lasting until 7:30 A. M. of the 7th.

"The first three were slight, and the fourth one quite severe; on looking out upon the crater, all fire had disappeared from the new lake. At about 2 or 3 A. M. the fire had disappeared from Halemaumau. During the night, while the shaking was going on, all hands were up in the sitting-room, not knowing what would go.

"On the morning of the 7th, after the mist and smoke had cleared away, it was discovered that all the bluffs surrounding Halemaumau had disappeared during the night. They, and the path formerly traveled to go from the new lake to the old one, and quite a piece on the mountain-side of old lake had all fallen away, forming one large chasm.

"There have also been several rents in the ground—one on the road to Kilauea-iki, and three on the Keauhou road. Two of them were cracks across the road, which I had bridged over. The other is a large hole where there was a cave, and the road bed had all fallen in. I have cut a new path around it. No other damage has been done that I have heard of up to writing.

"Last night, March 7th, all in the crater was in total darkness, excepting a few small lights from previous flows.

"March 8th, 7 P. M., 1886.

"My guide has just returned from the place of the burning lakes. There is at present no fire to be seen. In the place where the new lake was there is a deep hole, and from there to Halemaumau, all that part formerly used as a path from the new lake to Halemaumau, along with the Little Beggar, has fallen in, and forms a deep valley. At Halemaumau there is no fire to be seen, and no bottom.

"From the account that I had from Mr. Lentz in 1880, just before the Hilo flow, the fire disappeared there, leaving a bottomless pit for a week or more, when the fire returned. J. H. MABY."

No outflow of lava has ever been found in connection with this subsidence, but new, large and deep rents found in the neighborhood immediately afterwards with a smell of fire in them, indicate that the subsided lavas disposed of themselves by opening new rents or filling up old ones.

Mr. J. S. Emerson, of the Government Survey, arrived at Kilauea on March 24th, seventeen and a half days after the disappearance of the lavas and partial subsidence of the floor of the crater, and remained there till April the 12th, examining and surveying. During his stay "no molten lava was anywhere visible in the entire crater." There were merely red-hot places which had not cooled off.

On this occasion the main floor of the crater had not subsided, as was the case in former years, more especially in 1840 and in 1868. What had subsided on March the 6th, 1886, was a triangular space

about 3,350 feet on each side—forming an equilateral triangle—and which included the lava lake and cone of Halemaumau. Mr. Emerson estimated that the molten lava in Halemaumau "sank within a few hours a vertical distance of 587 to 597 feet, disappearing in the depths below." This depth, however, was only found at the central part of the floor of the break-down, where was a circular pit about 600 feet in diameter in the shape of a funnel, the bottom of which was estimated to be 275 feet below the general floor of the triangular subsided area, which averaged less than 200 feet below the rim, or floor of the crater of Kilauea in this neighborhood. It seems worthy of note that Mr. Emerson observed at the very bottom of this central conical pit of Halemaumau "an apparently smooth surface of black *pahoehoe*," * * in the shape of an equilateral triangle twenty-five feet on a side."

Soon after his visit, smoke and vapor, and other signs of returning fires became visible at the bottom of the great chasm. Prof. Van Slyke, visiting Kilauea in July following, found a cone in the bottom of the crater, with molten lavas, in the place of the funnel-shaped central pit. From this time the cone and central lava lake kept continually rising within the break-down, so that by October of the same year, when Mr. F. S. Dodge, of the Government Survey, visited it with the object of reporting its condition, he found a fair sized volcano or an irregular truncated cone, over one thousand feet in diameter at the top, with a lava lake in the centre of it, occupying all the central portion of the triangular pit, and with its summit about on a level with the general floor of the crater in that neighborhood. In *Science*, Volume IX., No. 212, (New York) pages 183 and 184, are to be found good phototypes of the chasm just after the subsidence, and of the cone of Halemaumau as it had risen up again in October, 1886, with description, by C. H. Hitchcock. There is also, page 182, a good phototype of the cavity once occupied by the new lake close by Halemaumau, also maps of the crater of Kilauea, surveyed by Mr. Emerson, after the subsidence, and of Halemaumau in October, 1886, from the survey of Mr. Dodge.

Since the latter date, the lake and cone of Halemaumau have been more or less steadily rising, and the lavas overflowing into the moat betwen the crater and the cliffs formed by the break-down.

There seem to be some interesting points in connection with this subsidence of lava in a small volcano and its gradual return. The precipices formed by the break-down form, roughly, three sides of an equilateral triangle corresponding in direction to the three coast lines of the volcano Haleakala—that is, of East Maui. We have suggested in Chapter VI. that the equilateral triangle is the typical form of a volcanic island. A volcano we have also seen is probably situated at the intersection of two or more grand fissures extending down to the molten substratum. The break-down seems to reveal to us the equi-

lateral triangle again at the nucleus, or at the intersection of at least two fissures. It may be remarked here, that these fault precipices forming an equilateral triangle must be inclined to each other at an angle of 60° neither more or less.

Not the least interesting circumstance about this cone or crater of Halemaumau is the fact that, since its first re-appearance in June, 1886, it has been slowly and steadily rising bodily. The cone, no doubt, receives accessions of matter from the splutterings of the internal lava lake, as well as by outpours of lava through the sides. But, besides all this, the evidence is clear that it is rising up bodily with the lavas. The molten lava seems to get underneath it, and as the liquid rises in the centre it forms a head of liquid to raise the whole cone, the base of which acts as if it were the piston of a hydraulic press. The weight which can be lifted by such a machine is only limited by the area of the piston, whilst the distance lifted and the speed of the piston is only limited by the supply of liquid. We suspect that just such a force-pump action has raised Mauna Loa bodily to the extent shown at the fault fissures parallel to the three coast lines. If this should prove to be the case, on further more careful examination, it would exhibit an instance of Beaumont's volcanic *sous-levement*, which we see acting on all oceanic active volcanic islands, and quite independent of any result of tangential pressure, such as is concerned in the elevation of great continental areas. It is easily conceivable how such a pumping elevatory action may go on locally in a generally subsiding area.

We would observe that some of these great fault fissures on Mauna Loa are at a less distance from each other than twenty miles—which seems to be the average distance apart of the main fissures of the group—and which fact we have referred to the effect of the thickness of the earth's solid crust in this region. But this is what we ought to expect if the pumping-up action which we have seen to be going on in the little volcano of Halemaumau has also been operating on Mauna Loa; for the injection of horizontal sheets of molten matter under the pressure of the head of liquid in the main central duct, might occur at any depth between the surface and the bottom of the solid crust raised, or at less than twenty miles deep. The distance apart of such fissures would then be regulated by the depth at which the injection of the approximately horizontal sheets of liquid occur. A great central area of each mountain might thus be lifted up by the hydrostatic pressure of a column of liquid of less mean density than the solid material of the mountain, because the portion lifted is in the form of a cone, and only represents a column of solid matter to be raised, equal to the average thickness between the summit and the fault fissures on the sides of the mountain where the lift ceases.

It seems evident that the processes which produced the break-down in Kilauea in 1886 have been operative in producing Kilauea itself,

and the other two great calderas of the group. The relation of the sides of the triangular pit to the sides of Kilauea as a whole, is evident on inspection of the Government Survey Map by Mr. Dodge. It may be worth noting also that the new lake occupies a position in the last break-down analogous to that of the small crater of Kilauea-iki to Kilauea. It has sometimes suggested itself to us that the two great active calderas of Hawaii may owe the present elevation of their sides above the usual level of the lavas, to the mountains on which they exist—or at least a large central portion of them—having been faulted and pumped up in the way we have pointed out. They are approximately the same depth, and this depth—or height of the crater walls—agrees with the height of the fault precipices which surround Mauna Loa in the form of a roughly equilateral triangle.

The rising lavas in the central ducts of Mauna Loa and Kilauea, may have pumped up and faulted up the central portions of the mountains formed by their own overflows, just as we see before our eyes the rising lava column in Halemaumau pumping up the cone around it, formed by its own outflows and splutterings; the result of both actions being, that the rim of the craters keep higher than the surface of the liquid lava columns.

The subsidence in Kilauea of March 6th, 1886, does not compare with that of 1840 or of 1868. In the first named year, Prof. Dana estimated that an area 12,000 feet long by 3,000 feet in mean width sank down 400 feet. This gives a cubic content some five times greater than that of the subsided region in 1886, so that it only took nine or ten months for the lavas to fill up the pit of this last year and rise to nearly their level before the break-down.

On January 16th, 1887, six years and two months after the 1880 outbreak on Mauna Loa—the lavas in Kilauea being now high and full—a new eruption broke out on that mountain. We present the following account of it gathered from local newspapers, as well as from the verbal accounts of many eye-witnesses.

A correspondent of the *Hawaiian Gazette* of Jan. 25th, writing from Mahukona, sixty miles to the northward of Mauna Loa, but in full view of the summit, says:

"On Sunday, January 16, at two or three minutes to 9 P. M., Mr. and Mrs. Smithies were sitting on the veranda, when they saw a stream of fire go up into the air from Mokuaweoweo. It lasted until eleven o'clock. Nothing was seen on Monday night, but on Tuesday and Wednesday we saw the reflection splendidly. It was also visible last night, (Thursday.)"

As the light and the vapors from the upper orifice of eruption on the south side of Mauna Loa, (Pohakuohanalei, of Kau,) would appear from Mahukona to be nearly over the very summit of Mauna Loa, there may be some doubt whether there was any actual eruption in the crater of Mokuaweoweo. The Rev. E. Baker, on visiting it shortly after

the eruption,. saw however, a long new crack along its floor from which the gases may have first arisen.

Let us remark however, that this is the usual course of events; Mokuaweoweo, the summit crater, almost invariably first shows itself active. The lava and imprisoned gases burst through the bottom of the crater and exhibit themselves in a great illuminated cloud thousands of feet above the top of the mountain. The weather had been very rainy for many weeks previously, as is usual at this period of the year, and the top of Mauna Loa was covered with snow.

The light over the summit was seen for a few hours only when it ceased, but a constant succesion of more or less violent earthquakes was felt afterwards, on the flanks of the mountain from Kona and Kau round to Hilo. On Monday and Tuesday these earthquakes were almost incessant, with a shock now and then of fearful violence. Different persons counted from five to six hundred shocks in the two days and then gave up counting because the shaking became continuous. About 4 P. M., on Tuesday, the 18th, at the moment when an unusually violent series of earthquakes was experienced at Kahuku, Kau, on the south side of Mauna Loa, a fissure opened about ten miles to the north-westward of that place, at an elevation of from 5,000 to 6,000 feet above the sea level, and a series of fountains of molten lava burst out along the line of crack. On the 20th Jan., two days afterwards, parties who visited the spot counted fifteen lava fountains —some of them 200 feet high—along the line of fissure up and down the mountain, or north 30° east, and extending two to three miles. This rent in the mountain is not far from that of the eruption of 1868, but the outbreak took place some seven miles to the northward and a little westward of the spot where the four great fountains of 1868 broke out. At daybreak on the 19th January, (next morning) the lava stream from these fountains crossed the Government road, and the same evening it reached the sea, some eighteen miles from the fountains, and just to the westward of the spot where the 1868 flow entered the sea. The lava continued running for about fifteen days, the latter part of the time under its own cooled crust, forming an a-a stream of various widths, from a few hundred feet to one or two miles, and of different depths, from eight or ten feet up to twenty feet or more. In hollow places the lava was no doubt much deeper, and in the sea it encroached from 200 to 500 feet over a space about 4,000 feet long. At the edge of this flow, in the sea, soundings give twenty to thirty fathoms. Earthquakes continued for some days after the outburst of lava, but they were less frequent and finally ceased with the lava flow.

We append the following discription of this flow and the lava fountains, as seen by Mr. W. E. Rowell, at close quarters, on the 23d January, or five days after the outbreak. Mr. Rowell is a civil engineer, and his account of what he actually saw may be relied upon as the evidence of a thoroughly competent witness:

"THE SOURCE OF THE FLOW, JANUARY 23.

"The following description of the flow, by Mr. W. E. Rowell, will give our readers a good idea of its magnificence. Mr. Rowell ascended the mountain to the source, on January 23d, and carefully studied its peculiar features and aspects, as will be seen in his description:"

"A lava flow of such large volume as the present must change its features so rapidly that different observers recording the views at different times will seem to make statements which seriously conflict. All I can pretend to give is the appearance of the flow from my points of view during one day, January 23d. Leaving the Government road a little west of the flow of '68, about 4 A. M., I started on foot, with the light at the source of the flow for a guide, picking my way over the ancient flows, through the bush and *koa* timber, making as near a 'bee line' as the ground would permit. Daylight found me in the scrubby woods, which grow lower down than the more open *koa*. An hour later I reached a ridge which overlooked the flow at an elevation of 3,400 feet above the level of the sea. It was here an open river, with well-defined banks, running at the rate of six or eight miles an hour, and the clear width could not be less than 150 feet and was probably 200 feet. The view of the river alone was enough to pay for the climb. A large rock stood in the middle of the stream and the molten fluid piled up against it, almost going over it at times, so that it was impossible not to watch it for a time to see it carried away. It gave no signs of yielding, but it seemed to grow in size. The stream did not show the smooth surface of a perfect fluid, as for instance that of molten iron, but seemed filled with lumps or grains, occasionally carrying black blotches along on its surface, that the imagination could convert into fragments of a boat or carcasses of animals. Going on, my course took me away from the flow, which made a considerable bend to the west. At 9 o'clock I reached the upper limit of the *koa* forest and could see the fountain of lava boiling up behind black walls of fresh lava. The ground for a mile or two below the source of the flow, having less fall than lower down, the lava had spread out so far on each side that it was impossible, looking at it from one side, to form any well defined idea of its full width and shape.

"At ten o'clock I was abreast of the boiling mass, whence arose the dense volume of vapor which had been the beacon towards which I had been steering. In the midst of such desolation it was very hard to judge accurately of height and distance, but making as careful estimates as possible, I judged that I had reached a point about 4,000 feet east of the lava fountain. It was a surprise and a pleasure to discover a party of four persons on an elevation a few hundred yards away, who had arrived at the same time as myself. The fountain seemed to be between two walls of fresh lava which had been formed by fragments of lava falling and cooling on one another until a height of from fifteen to forty feet had been reached. These walls

were very steep on the outside and the top line was very irregular, rising to a point here and falling away to a sharp notch just beyond, and again continuing nearly uniform for a considerable distance. For a mile seaward and considerably more than a mile toward the mountain, these walls extended in a straight line as nearly as we could judge looking from one side. They seemed to be marking the sides of a crevice or channel, down which the stream of lava was rapidly running from some place higher up the mountain; or else it was building up from below, at various points in all this line. With a prismatic compass the course of these walls was made from the direction of the sea towards the summit north 3° east.

"The lava spouted up, not as a liquid would be forced from a pipe by hydrostatic pressure, but as if a powerful jet of gas or steam coming through the mass threw up tons at a time from fifty to one hundred feet high. That which reached the highest and was thinly scattered turned black, so that the spray from the fiery column fell down like gravel, only it had the peculiar appearance of floating down as if it were very light.

"The main fountain occupied a length of more than 100 feet in the channel, and every mass that boiled up fell away in a southerly direction, as if it had an acquired momentum down hill before being thrown up, or else was projected at an angle and not perpendicularly. Away down three-fourths of a mile a jet of lava occasionally appeared above the black walls, and at a still greater distance mountainward another fountain appeared, spouting continuously, but of much less volume than the one close to us. The two walls seemed to be from twenty to forty feet apart, and all of the lava that was thrown up fell back and was retained between them until the lower jet spoken of was passed

"Above the main fountain the walls averaged much lower than below, as if comparatively little lava had been spouted up above this point. Comparing the appearance of the main fountain with the same thing as seen from the steamer on the morning of the 20th, the volume seemed to have diminished one-half.

"Later observers report quite a different appearance at the source of this great flow, so I judge that the changes have been very rapid.

"An immense volume of lava has run down the side of the mountain, and this flow is very much larger than that of 1868.

"W. E. Rowell."

We also add extracts from a letter written by the Rev. S. E. Bishop, who visited the flow as special correspondent of the *Hawaiian Gazette*, and which was published in that paper of the 8th February: "Mr. Bishop is well known in the scientific world as the discoverer of that appendage to the sun, which has been called after him the 'Cercle de Bishop;' he also wrote the third prize essay on the after-glows following the Krakatoa eruption, contending against some of the most brilliant thinkers of the day." The portions we have omitted from this

letter are mainly of local interest only. Mr. Bishop arrived off the flow on the evening of February 1st, when the lava had nearly ceased running:

"At daylight we steamed in some six miles from where we had lain around for the night. The same dark cloud kept its station marking the course of the hot flow directly beneath it. Mauna Loa's vast dome now cloudless, was far inland, but dim in the haze. To the right stretched away the long low south point of the island. Inland about six miles the groves and buildings of Jones' ranch broke the line of the long slope. Close to this could be seen the black line of the pahoehoe flow of '68, terminating broadly at the sea near Marchant's Hill, two or three miles to the right. In front were other and older flows, among which, broader and blacker than the rest, spreading lawless and ragged down the stony slope to the level bottoms, lay hot and tumultuous the flow of '87.

"The hot air over the flow rises in a strong current. At the height of perhaps 3,000 feet from the surface it rarifies and chills, condensing the aqueous vapor with which all air is loaded, thus forming a dark massive cloud exactly over the flow and marking its course. Some seven miles inland this line of cloud made a sharp turn or elbow to the northward, directly towards the summit crater of Mokuaweoweo. We had the pillar of cloud by day, but, to our chagrin, no pillar of fire by night. Noting the length of this cloud, and where it appeared to terminate, I estimated the length of the flow at from sixteen to twenty miles, and the head of it very much more than twice as far inland as Kahuku Ranch.

"The front of the new lava was easily distinguished as we steamed up to it by its black and rugged piles and out-jetting points, in contrast with the whitish mossy sea-line and older rocks on each side. From most parts of its shore small clouds of steam were rising thickly. From a cove near its south side a large jet of strong steam rolled continuously, and clouds of this swept up inland. Hereabouts for fifty feet out from shore the water was covered with visible steam. We stopped near the south side, dropped our boats and rapidly landed the whole crowd of 200 visitors, including natives. We climbed up the rocks some twenty feet upon an old pahoehoe flow. This was a mass of hummocks, wrinkles and bubble caves, but quite easily clambered over. Many large sea-worn boulders and much sand had been flung up 100 feet or more inland over this by the tidal wave of 1868. A *lauhala* grove was on one spot of sand, and the green streamers of the *maia pilo* lay in profusion on the lava with their great, lovely plumed white flowers.

"But to the left the vast, hideous mounds of Pele's awful work enchained our eyes. Like enormous piles of brownish coal, but indescribably more ragged, stretched inland over the low, rising plain for two miles to the mountain slope, in a substantially direct line, this

bank of hot cinder, averaging twenty-five feet high on the edge, but rising towards the middle to an average height of forty feet. Many points must have been twenty feet or more above the general level, if the word level can be used of such chaotic masses of ruin. The sides of the mass were steep and crumbling, composed of large, ragged clinkers and fine cinder intermingled, difficult enough to climb on its jagged but yielding footing. The whole seemed like a colossal embankment, as if 10,000 cyclopean trains of mastodon cars had been dumping the rocks of Mauna Loa for a century towards the sea.

"All was shimmering with heat. We found a way up the crumbling heaps of pumice and slag, and reckless of singeing boots and hot blasts from below, scrambled around among the sharp and ragged pinnacles to higher points, whence only a wider waste and wilder desolation were to be seen. At one point a party were charring their sticks in a red-hot hole. At another was a rent fifty feet long, where, some fifteen feet below, was a great glow of almost white heat along its length. There was almost an entire absence of noxious odors and gases, and even of steam, though sudden hot blasts of air would often drive one aside.

"The sea front was the most impressive. Here the great embankment rolled over a cliff some twenty feet, making slopes of from fifty to seventy feet high from the water along a shore of from three-fourths to a whole mile in length. I consider it certainly not less than the former distance. This sea front is broken into a succession of long, ragged capes and deep coves, with many wide beaches of coarse, black gravel, thrown up by the waves, looking like shiny nut coal. Here and there huge round boulders, bristling with adhering cinders, lay half buried in the ragged slopes. One of these was visited and found to be twenty feet long. Are they fragments of the mountain's massive throat, torn by the outrushing flood, which half melts and rounds them? The water near the shore was generally from 100 to 120 degrees Fahrenheit, and in spots much higher and steaming.

"The northwest side of the floor presents a straight solid embankment, apparently thirty or forty feet high, at an angle of 40° to the coast-line, stretching northward for apparently a mile or more, then turning inland. Evidently the breadth of the stream is fully one and a half miles at a short distance inland. I judge that on the lower slope are deposited three square miles of clinkers, thirty or forty feet in depth. The flow evidently overreaches the original coast-line from 200 to 500 feet, making some thirty acres of new land. Much of this last is of great depth, soundings being from twenty to thirty fathoms close to the shore. A large or rapid extension of coast is impossible where such a depth is to be filled in.

"It is comparatively easy to estimate the amount of forces involved, and the colossal dimensions of the great tidal wall of mingled white-hot lava and scoria foam that rolled so steadily and massively

forward to the sea, which it first reached more than two weeks before. One can perhaps partially imagine how that tide of fire and rocks of near a mile wide rolled for a week over the shore into the deep and convulsed ocean. But I have never seen work of that sort, and I have no powers of imagination to conceive the awful splendor of the downward charge of that mile-broad deluge of fire, nor the horror of tornado clash and roar with which that vast wall of rolling rock and cinder pressed forward over the land, piling up on the plain, crashing into the sea. We saw but the dead and dying remains—dreadful, dark and silent.

"We were very fortunate on the following day at Hilo, to meet Mr. G. H. Paty, who had just returned from Kahuku, being one of Rev. Mr. Baker's party to visit the head of the flow, where they spent Friday night, the 28th ultimo. I obtained from Mr. Paty the following facts: The altitude of the last point of emission is 5,700 feet by aneroid. Distance from Jones' ranch sixteen miles by pedometer, route quite direct through mostly *koa* woods; estimated distance from sea, twenty miles. Source of the flow is above the timber, among sparse *ohia* and *ohelo.* It has formed five small cones in a line of three miles on a fissure evidently much longer. During their visit the output was confined to a lower cone, about 50 feet high. A fountain was playing about 155 feet high, falling into a basin of lava fifty feet wide, from which issued a narrow stream of pure white fire twenty-five feet wide, with a velocity of fifteen miles an hour. The fountain seemed brightly white in the daytime. Much pumice-like stone was flung out, and the clink and crash of the falling liquid was tremendous. Mr. Baker was struck by a fragment of falling pumice, which he preserved as a memento.

"The lava in its descent appeared to be making a-a exclusively. Pahoehoe was seen, however, mingled in some portions of the flow visited. The lava was bright on Sunday night, the 30th, as seen from Kahuku Ranch near by, and much glow was visible on Monday morning both there and at the source. Mr. Jones reported it to have reached the sea in twenty-six hours from the start. Mr. Paty visited it near Jones', making a-a. It was running about four miles an hour. The breadth of the whole stream there was half a mile.

"I can add no more of special interest about the eruption of 1887, except that it is unquestionably much greater in quantity than that of 1868, being more than twice the length of the latter, and of greater depth on the ground. I would, however, take this opportunity of stating an interesting volcanic fact observed in steaming around the south point of Hawaii—a fact which, so far as I know, has not been hitherto remarked. My attention was specially directed by Hon. A. F. Judd to a remarkable surface-layer of yellow ochre, or similar matter, of many feet in depth. This I could see extending, as a conspicuous object, over the entire length of eight miles of the peculiar bluff which runs from Kahuku Ranch to the South Cape.

"On rounding the South Cape, this layer was still conspicuous along the coast. Occasionally a recent lava flow of small breadth lay over it. A small, steep cinder cone on the shore was overlaid by the yellow stratum, like snow on a roof. I at once perceived that it was somewhat analagous to snow. It was manifestly nothing more nor less than a thick layer of yellow ashes, distributed from some eruption in Kau, probably thousands of years ago. The yellow layer continued along the coast until reaching Honuapo fifteen miles from the Cape, and ten miles from Kahuku bluff. At Honuapo a bluff appeared, formed by the sea eating into the end of the very broad and long mound upon which Naalehu cane fields are situated. This bluff disclosed the peculiar stratification of a cinder cone, like Punchbowl or Koko Head, on Oahu. The color of the rock and cinder was of the same peculiar yellow as the ash-layer which we traced to it. We are thus enabled to determine the very remarkable and important fact that at a recent period, although pre-historic, the Honuapo or Naalehu mound was formed by an explosive eruption of yellow cinder, which covered at least 100 square miles to the westward with yellow ashes several feet in thickness. It must have belonged to the larger class of explosive eruptions. I hereby file my caveat for this discovery, in case no one has recorded a patent of prior date.

"S. E. Bishop."

GENERAL REMARKS ON THE 1887 ERUPTION ON MAUNA LOA.

It will be observed that this outbreak occurred in the month of January, the month in which happened six out of the eighteen eruptions in sixty-four years as per our statement, while six others were in the months of November, December, February and March. Thus twelve out of eighteen eruptions in sixty-four years broke out in the five rainy months of the year. The weather had been remarkably rainy previous to January 15th, and the summit of Mauna Loa was well covered with snow. There is evidently a close connection between rainy seasons and the moment of an outbreak. It is equally clear, however, from the facts presented in our tabular statement that volcanic eruptions on Hawaii depend upon other circumstances than rainy seasons.

The superficial waters from rain and snow gaining access to the molten lavas in the red and white-hot ducts and fissures of the mountain may well cause explosions of steam, open out the rents, and allow the molten lava, already under a head of pressure, to escape. The resulting expansive gases would mostly escape with the first outburst, or at least during the earlier stages of an eruption. These explosions may determine the moment of an eruption; they may precipitate a catastrophe, but they can be no more the cause of the eruptions than would be the conjunction or opposition of the sun and moon or other planetary bodies, which are also believed, on apparently good grounds, to determine in many cases the moment of a volcanic eruption.

These are merely accidental impulses which pull the trigger connected with a combination of mechanical powers, the effects of which had been gradually accumulating, and which must have resulted in a catastrophe whether these accidental impulses had prematurely released the combination or not. The lavas are constantly and steadily rising in the central conduits of the mountains, and they must break out ultimately, even when there is no rain whatever—as indeed they often do. In fine, the experience of sixty-four years shows that rainy seasons or heavy rains—and which usually occur every year—have not caused an outflow of lava on Hawaii at all in fifty-four out of sixty-four years, and then only at the end of 9, 8, 3, 9, 3, 4, 9, 3 and 7 years after the last outbreak, and of these many do not seem to have been influenced by wet seasons. Rains and rainy weather do not produce an eruption till the internal machinery of the mountains—operated by quite other causes—is prepared to produce one.

With reference to the lava fountains of this flow, it will be observed that Mr. Rowell says: "The lavas spouted up, not as a liquid would be forced from a pipe by hydrostatic pressure, but as if a powerful jet of gas or steam coming through the mass threw up tons at a time from 50 to 100 feet high." This appearance is just what is to be expected under the circumstances as described by Mr. Rowell and all the other observers. Speaking of the walls of the fissure, Mr. Rowell says: "They seem to be marking the sides of a crevice or channel down which the stream of lava was rapidly running from some place higher up the mountain; or else it was building up from below at various points all on this line." * * * "This main fountain occupied a length of more than a hundred feet in the channel, and every mass that boiled up fell away in a southwardly direction, as if it had acquired momentum down hill before being thrown up, or else was projected at an angle and not perpendicularly."

Some observers reported that they considered the fountains to be merely those portions of the lava torrent where obstructions were met with in its downward course, and where, therefore, lava was projected in a slanting direction into the air. The same observers noticed also the appearance of expansive gases escaping with these jets or fountains, and especially the wheezing and shrieking noises. The fact seems to be that this was a lava stream which was running rapidly down the upper part of a fissure of irregular width, and which was sometimes entirely closed in above and sometimes open. It therefore presented the combined appearance of a liquid escaping from a pipe under a head of pressure, and of a torrent rapidly flowing down a steep declivity, and in the bed of which were permanent projecting rocks partially obstructing its course. In such an irregular passage partly closed in and partly open, above, the molten lava rushing down at the rate, perhaps, of twenty-five miles an hour or more, would, when it arrived at a narrower part of the tunnel, throw

up a column of liquid, produced jointly by hydrostatic pressure and the rapidity of its descent. It is evident also that, in an action of this kind, immense quantities of air must become entangled and compressed, which will escape with the lavas heated and expanded. Whatever water may have got access to the lava in its course—and the mountain being covered with snow, it is probable that a great deal did—would escape in steam with the jets.

We would call attention to a familiar instance of explosive action in a purely hydraulic operation; that is, at the nozzle of the hose of a fire-engine when working. If the water in the cistern from which the supply is drawn happens to be somewhat low, the suction-pipe will draw air in a little whirlpool from the surface of the water. This air will be passed through the pumps and highly compressed, so that when it finally escapes at the nozzle it produces a succession of reports like pistol shots. This is just what a lava stream running through an irregular passage or tunnel under a head of its own liquid might also do; that is, suck in air and compress it, so that when the lava escaped at the first opening, a series of explosions of compressed and highly heated air might occur. This principle, indeed, may often apply also when lavas accidentally draw *water* from any source, as when they escape there might be a constant succession of explosions of red-hot water. In such cases this would immediately expand into steam and become visible, appearing like the globes of vapor or "balls of cotton," so often described in volcanic eruptions. In certain cases, therefore, these explosions of steam may be the result of the out-rush of lava—not its cause. This remark does not apply to such explosive eruptions of steam mainly as those of Krakatoa or Tarawera, which were evidently produced by water getting to the hot rocks or lavas from the sea in the one, and from fresh water lakes in the other case; indeed, the last-named eruption, as we have elsewhere observed, has been called by the best authorities on the subject a gigantic exhibition of geyser action, or of secondary volcanic action.

We have before us two photographs of two of the main fountains of the 1887 flow, taken close to them, from a side view, on the 18th January. They are not taken by the instantaneous process, and show therefore the average outline of these fountains. They are as nearly as possible perpendicular, though showing darker shading on the upper side, indicating that the fall was towards the sea, but the outline forms an almost perfect parabolic curve, the whole being, as we observed before, nearly perpendicular, and about as high as wide. These photographs show no smoke, and Mr. C. Furneaux, who obtained them from the photographer, informs us that there was little or no smoke over these fountains at the time, although an immense volume of smoke was rising from an upper orifice, and was passing at the back of them at the moment; but moving smoke would only take in a photograph by a process not instantaneous in its action, as a

general shadow. This shows that even photographic representations of certain volcanic phenomena require to be carefully analysed. It is perhaps unnecessary to remark that, as a picture of the phenomenon, these photographs of incandescent lava fountains—taken of course in daylight—are a complete failure, showing merely a shadowy cone. They are quite valuable, however, as a means of indicating their character from the direction and the regularity of their mean outline. We have, however, an admirable summary and supplement to the various photographs and descriptions of this great eruption in an oil painting by Mr. C. Furneaux, from a sketch by him in colors, of the wonderful scene presented to the view of the party on board the steamer on the night of the 29th January. In the foreground, to the right, appears the fault precipice of Mamalu, jutting out some miles into the sea, whose dancing waves are lighted up with the ruddy glow of volcanic fires. In the centre of the picture appears the volcanic cone, from the summit of which the white-hot molten lava fountain glares like a column of electric light, while two glowing lava streams, one twenty miles long, run down the slope, which unite near the sea, and falling into it, show a long line of lights along the shore, with clouds of steam rising from them. It should be observed that this cone, nearly 6,000 feet high above the sea level, is hardly visible in daylight when all is clear, as it is a kind of spur or shoulder on the face of Mauna Loa, so that when both are seen together in clear weather, the background of lava on Mauna Loa is almost indistinguishable from the same lavas of the cone or shoulder. The intense light now on the summit of the latter, however, and the background of Mauna Loa being enveloped in smoke, fog and darkness, brings out the fact of the existence of this shoulder on Mauna Loa, and which indeed the Government survey maps indicate. This spur or shoulder, is in fact, the result of the intermediate, or north 30° east fissure, which appears to exist here. A fissure which is in line with the longer axis of the crater of Mokuaweoweo, and with the crack which now appears along its floor. The lavas of the great central duct have escaped along it from time to time, in past ages, and built up the shoulder, just as they have the ridge on the northeast side of the mountain. Mr. Emerson has recently discovered further clear indications of the corresponding fissure running east and west from Mokuaweoweo to Kealakekua—along which the 1877 flow erupted—in a series of pit craters and of cones on this precise line, which is exactly at an angle of 60° to the 1887 fissure and ridge. These fissures are precisely intermediate between the main fissures, 60° to each other, running parallel to the coast lines; that is to say, one is midway between the north and south fissure and the south 60° east fissure, and the other between the last and the north 60° west fissure.

It is seldom that an artist has an opportunity to paint from nature so complete and typical a volcanic eruption as this one; for not only

does there appear, from one point of view, the bright fountain of molten lava on the summit—so seldom seen elsewhere—with the fiery streams running down the mountain into the ocean; but there appears also, in this picture, a complete series of atmospheric, vapor and cloud effects, all quite distinct from each other in their nature and origin. Let it be remembered that the regular trade winds appear to be blowing, moving from the right hand side of the picture towards the left. To the right, above and beyond the slope of the cone appear the usual trade wind clouds, or such at least as usualy hang at a certain height on the slopes of Mauna Loa. Directly above the slope of the cone towards the sea, and at some height above the course of the fiery lava streams, appears a heavy bank of cloud strongly illuminated by the fires beneath it, and showing a lurid glare. This is essentially the same hanging cloud, described above by the Rev. S. E. Bishop, as remaining stationary over the course of the still heated lava stream, but of which the flow had stopped, and from which no gases whatever arose, other than heated air. This is evidently the same kind of cloud that we have described above as hanging over the reservoir of lava which was dammed up near Hilo in 1881, and Mr. Bishop, as will be seen, accounts for this hanging cloud of 1887 in the same way that we did that of 1881. From the summit of the cone, and apparently from the same spot as the lava fountain, an immense trail of volcanic smoke appears, blowing away to leeward in a horizontal stream, as well defined as if from the funnel of a gigantic steamer. This smoke issuing from the same fissure as the lava fountain and being in the same line of sight, appears in the picture as if it arose from the same orifice, but the view from other points showed that at this time it arose from an orifice on the same fissure, some little distance above the lava fountain. There is no apparent connection whatever between this moving stream of volcanic smoke and the stationary bank of cloud above the whole cone and the lava stream. At the sea, appears again a series of columns of steam, as the red-hot *a-a* and its molten contents crash into the water. These large volumes of steam show themselves independent also of the smoke-stream, the hanging cloud and the ordinary trade wind clouds, and they blow off to leeward and disperse. Again, there are light patches of vapors all along the course of the lava streams; caused no doubt, by the escape of whatever vapor of water may have got intermingled with the incandescent lava, as well as by the smouldering of burnt up vegetation in its course. To the left of the picture and to leeward, where the great volcanic smoke trail and the other vapors and clouds probably unite, there issue flashes of fork lightning, the usual accompaniment of great volcanic discharges. The whole picture seems to give as true and vivid a representation of a great typical volcanic eruption as could well be transferred to canvas.

Let us now turn to Kilauea at this period. The very first reports

from there after the date of the outburst on Mauna Loa, speak of the "very little activity of Kilauea," but which had previously been quite active. One report says: "Kilauea seems to have been transferred to Mauna Loa." This comparative repose of Kilauea continued during the whole time of the outflow on Mauna Loa, but when the latter ceased Kilauea revived. We have before us an instantaneous photograph of Halemaumau, taken from the top of one of its cones, on the 14th February, 1887, by Mr. Severin. This photograph is stated by him to show the first outflow of lava from the cone of Halemaumau after the outbreak on Mauna Loa, on the 16th January. At the date this photograph was taken, the Mauna Loa outflow had ceased two weeks. It shows the molten lava running into the moat between Halemaumau and the sides of the breakdown. It is an interesting picture, showing the renewal of activity in Kilauea after the stoppage of the flow on Mauna Loa, whilst the fiery lavas and ragged, black slags in the foreground, contrast with the scene in the background, where the majestic, gently sweeping dome of Mauna Loa—twenty miles wide not far from the top—is seen in the distance, covered with a mantle of pure white snow. But the melting snows provoke no new eruption on Mauna Loa. Its column of molten lava has just been tapped and drawn off to a safe level. But now, the dormant state of Kilauea, which appeared to exist during the outflow of Mauna Loa, is at an end. The lava has commenced to rise steadily again in Halemaumau, as it is no doubt doing also, in the concealed recesses of Mauna Loa. Judging from past experience, it will take at least from three to four years, and possibly more, before the "flood-level" is again reached on that mountain. "*Requiescat in pace.*"